MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

ARBORWAY ALTERNATIVES ANALYSIS

Final Report

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June 2001

TABLE OF CONTENTS

EXECUTIVE SUMMARY ES-1
1. PURPOSE OF THE STUDY 1
2. THE ARBORWAY STUDY CORRIDOR: CURRENT CONDITIONS AND SYSTEM CONSTRAINTS 2
2.1 Geographic Boundaries 2
2.2 Demographics 4
2.3 Street-Level Characteristics 4
2.3.1 South Huntington Avenue 4
2.3.2 Centre Street 5
2.3.3 South Street 6
2.3.4 Study Corridor North of Heath Street 7
2.4 MBTA Services to the Arborway Study Corridor 8
2.4.1 Rail Lines 8
2.4.2 Bus Service 9
2.4.3 Bus Ridership 9
2.4.4 Bus Schedule Adherence and Passenger Loads 9
2.4.5 Buses and Garages 9
3. EVALUATION FRAMEWORK 10
4. DESCRIPTION OF ALTERNATIVES 12
4.1 Light Rail Alternative 12
4.1.1 Vehicle characteristics 12
4.1.2 Light rail operating characteristics 12
4.1.3 Light rail implementation 14
4.2 CNG Bus Alternative 17
4.2.1 Vehicle characteristics 17
4.2.2 Operating characteristics 18
4.2.3 Implementation 18
5. EVALUATION OF ALTERNATIVES 21

Appendix A: Capital Costs
Appendix B: Operating and Maintenance Costs
Appendix C: Ridership and Air Quality Forecasts
Appendix D: Rail Network Simulation Model Technical Memorandum

LIST OF TABLES

Table 1: Evaluation Framework
Table 2: Evaluation Summary
Table 3: Evaluation Framework
Table 4: Light Rail Service Characteristics
Table 5: Summary of Light Rail Impacts on Parking
Table 6: Bus Route Characteristics
Table 7: Summary of CNG Bus Impacts on Parking
Table 8: Emissions
Table 9: Average Weekday Ridership
Table 10: Capital Costs to Implement Light Rail Service
Table 11: Capital Costs to Implement CNG Bus Service
Table 12: Evaluation Summary

LIST OF FIGURES

Figure 1: Arborway Study Corridor
Figure 2: Light Rail Route Map
Figure 3: CNG Bus Service Route Map

EXECUTIVE SUMMARY

Purpose and Background

The purpose of this study is to compare two alternatives for improving service between the Arborway corridor and downtown Boston:

- Light rail service between Forest Hills and Park Street;
- Compressed Natural Gas (CNG) bus service between Forest Hills and Park Street.

Light rail service between Forest Hills and Park Street entails the restoration of light rail service between Forest Hills and Heath Street ("the Arborway restoration project"). The Arborway restoration project is included in the Transit Systems Improvement regulation (310 CMR 7.36). That regulation allows substitution for a listed project if the listed project is infeasible due to adverse engineering, environmental or economic impacts. In January 1999, the Executive Office of Transportation and Construction (EOTC) petitioned the Department of Environmental Protection (DEP) to substitute CNG bus service for the Arborway restoration project. Subsequently, the DEP found that EOTC had not yet demonstrated that it is infeasible to restore light rail to the Arborway corridor, and specified additional requirements in an Administrative Consent Order and letter dated September 1, 2000.

A study was subsequently undertaken that analyzed the issues associated with light rail in the Arborway corridor (Analysis of Restoration of Light Rail to the Arborway Corridor, URS Corporation Group Consultants, 2001). Concurrently, the analysis described in the pages that follow was performed in order to identify the characteristics of a substitute project and compare that project to light rail restoration. In conjunction with the studies, four public meetings were held that involved the community in the process of clarifying the conceptual design and associated impacts of light rail service as well as the basis for comparing light rail service to CNG bus service.

Evaluation Framework

The framework for evaluating alternatives starts with six goals that capture a range of environmental, engineering, and economic considerations and are sensitive to the needs of the Arborway study area:

- Achieve regional air quality standards
- Maintain public safety
- Increase transit usage
- Preserve local business
- Develop an operationally effective solution
- Comply with the Americans with Disabilities Act

A proposed evaluation framework was presented to the public at a meeting in Jamaica Plain on February 28, 2001. The framework was subsequently revised to incorporate suggestions from the community. The full list of goals, objectives and criteria is shown in the table on the next page.

Table 1: Evaluation Framework

Goal	Objective	Criteria
Achieve regional air quality standards	- Comply with Clean Air Act/State Implementation Plan requirements	- Reduce emission of non-methane hydrocarbons, carbon monoxide, and nitrogen oxides
Maintain public safety	- Avoid obstructions to traffic flow	- Allow free passage of emergency vehicles
Increase transit usage	- Increase ridership - One-seat ride to Park Street - Improve schedule reliability - Improve passenger comfort	- Number of riders - Improve passenger waiting areas - Shorten trip time - Reduce crowding and increase number of seats
Preserve local business	- Maintain or improve access to businesses	- Preserve existing on-street parking - Maximize access to businesses by pedestrians, bicyclists, and other traffic
Develop an operationally effective solution	- Maintain overall system performance	- Impact on system reliability - Available maintenance and yard capacity - Compatible with safety goals - Adequate benefit-cost analysis
Comply with the Americans with Disabilities Act	- Ensure service accessibility	- Compliant vehicles, stations, bus stops

Description of the Light Rail Alternative

The existing Green Line "E" Line service would be extended beyond the current terminal at Heath Street to Forest Hills. The restored service would utilize light rail vehicles operated in two-car consists. There would be twenty-two stations between Forest Hills and Copley and three stations after Copley Station to Park Street. Total travel time would be about 35 minutes on average. Peak headways would be 6 minutes. This represents more frequent service than the "E" Line, which currently offers 8.5-minute peak headways. This service would replace the existing Route 39 bus service. Light rail restoration requires the purchase of vehicles and construction of track, power, signals, and stations.

Description of the CNG Bus Alternative

Service would be provided between Forest Hills and Park Street via 60-foot articulated buses powered by compressed natural gas (CNG). The bus would follow the existing Route 39 to Copley Station and Route 55 to Park Street Station, where it would terminate. Total travel time would be about 41 minutes on average. Peak headways would be 4 minutes, equal to the frequency of Route 39 today. The existing "E" Line LRV service would be unchanged. CNG bus service requires the purchase of vehicles and lengthening of bus stop zones. Amenities such as shelters, benches, kiosks, route maps, and signage would be provided.

Evaluation Summary

The table on the next page summarizes the comparison of the light rail and CNG bus alternatives. In summary, the alternatives produce roughly the same amount of pollutants at the regional and corridor levels and are therefore equal in terms of achievement of air quality standards. Under each alternative, total systemwide linked transit trips are about equal, with the light rail alternative associated with 811,000 regional transit trips and the CNG bus alternative associated with 812,200 regional transit trips. Neither of these represents a statistically significant increase in transit trips. The corridor ridership associated with the light rail alternative (34,850) would be slightly lower than that of the CNG bus alternative (36,190). Therefore, the alternatives can be considered equal in terms of their ability to increase transit usage.

The alternatives differ most significantly in terms of the characteristics that affect access to businesses, public safety, and operational effectiveness. The light rail alternative poses significant engineering challenges to design and construct the service in a way that allows safe implementation of the desired level of service. The character and use of the street and roadway will be affected during construction and after implementation. The CNG bus service does not have these impacts. The CNG bus alternative adds system capacity through the use of higher-capacity articulated buses. The light rail alternative competes for capacity with the other Green Line branches through Copley. The light rail alternative requires greater cost for implementation than does the CNG bus alternative.

Table 2: Evaluation Summary

Goals and Objectives	Criteria	Light Rail Alt.	CNG Bus Alt.
Achieve regional air quality standards	NMHC		
	- Region	69,449 Kg/day	69,445 Kg/day
	- Corridor	4,556 Kg/day	4,552 Kg/day
	Nitrogen Oxide		
	- Region	134,002 Kg/day	134,031 Kg/day
	- Corridor	5,755 Kg/day	5,782 Kg/day
	Carbon Monoxide		
	- Region	669,221 Kg/day	669,201 Kg/day
	- Corridor	60,759 Kg/day	60,742 Kg/day
Increase transit usage	Total systemwide linked transit trips	811,000	812,200
	Corridor transit trips	34,850	36,190
Maintain public safety	Barriers to free passage of emergency vehicles	Barriers exist	No barriers
Preserve local business	Traffic impacts due to construction?	Significant	Minor
	Reduction in on-street parking.	120 spaces	58 spaces
Develop an operationally effective solution	Capital cost	$76.7 million	$24.7million
	O&M cost for all transit between Forest Hills and Park Street	$19.4 million	$16.7 million
	Net increase in operating cost over current Route 39 service.	$7.1 million	$4.2 million
	Available operating capacity?	Requires reductions in other Green Line service	Yes
	Available maintenance and yard capacity?	Modifications required	Yes
Comply with ADA	Impacts to achieve compliance with Americans with Disabilities Act	Significant	Minor

1. PURPOSE OF THE STUDY

The purpose of this study is to compare two alternatives for improving service between the Arborway corridor and downtown Boston:

- Light rail service between Forest Hills and Park Street;
- Compressed Natural Gas (CNG) bus service between Forest Hills and Park Street.

Light rail service between Forest Hills and Park Street entails the restoration of light rail service between Forest Hills and Heath Street ("the Arborway restoration project"). The Arborway restoration project is included in the Transit Systems Improvement regulation (310 CMR 7.36). That regulation allows substitution for a listed project if the listed project is infeasible due to adverse engineering, environmental or economic impacts. In January 1999, the Executive Office of Transportation and Construction (EOTC) petitioned the Department of Environmental Protection (DEP) to substitute CNG bus service for the Arborway restoration project. The DEP found that the EOTC had not yet demonstrated that it is infeasible to restore light rail to the Arborway corridor, and specified additional requirements in an Administrative Consent Order and letter dated September 1, 2000.

EOTC was also directed to conduct a public and community involvement process for the purpose of scoping and reviewing a revised infeasibility determination and, if necessary, a proposed alternative project. Four public meetings were held that involved the community in the process of clarifying the conceptual design and associated impacts of light rail service as well as the basis for comparing light rail service to CNG bus service.

The study described in this report addresses the analytical requirements specified by DEP by evaluating light rail service that provides a "one seat" ride to downtown with 6-minute peak headways. Additionally, this study makes extensive use of the report recently completed by the MBTA that analyzes the issues associated with light rail in the Arborway corridor (Analysis of Restoration of Light Rail to the Arborway, URS Corporation Group Consultants, 2001). The goals and objectives used to evaluate alternatives in this study capture environmental, engineering, and economic priorities. They also reflect public input and a commitment to pursue the most feasible and regionally beneficial transit improvement.

2. THE ARBORWAY STUDY CORRIDOR: CURRENT CONDITIONS AND SYSTEM CONSTRAINTS

The existing characteristics of the study corridor are described in order to understand the service that customers experience today. This is the environment that will affect the success of any alternative.

2.1 Geographic Boundaries

The Arborway study corridor, shown in the figure on the next page, extends from the Arborway/Forest Hills station in Jamaica Plain to Park Street Station, via Copley Square.

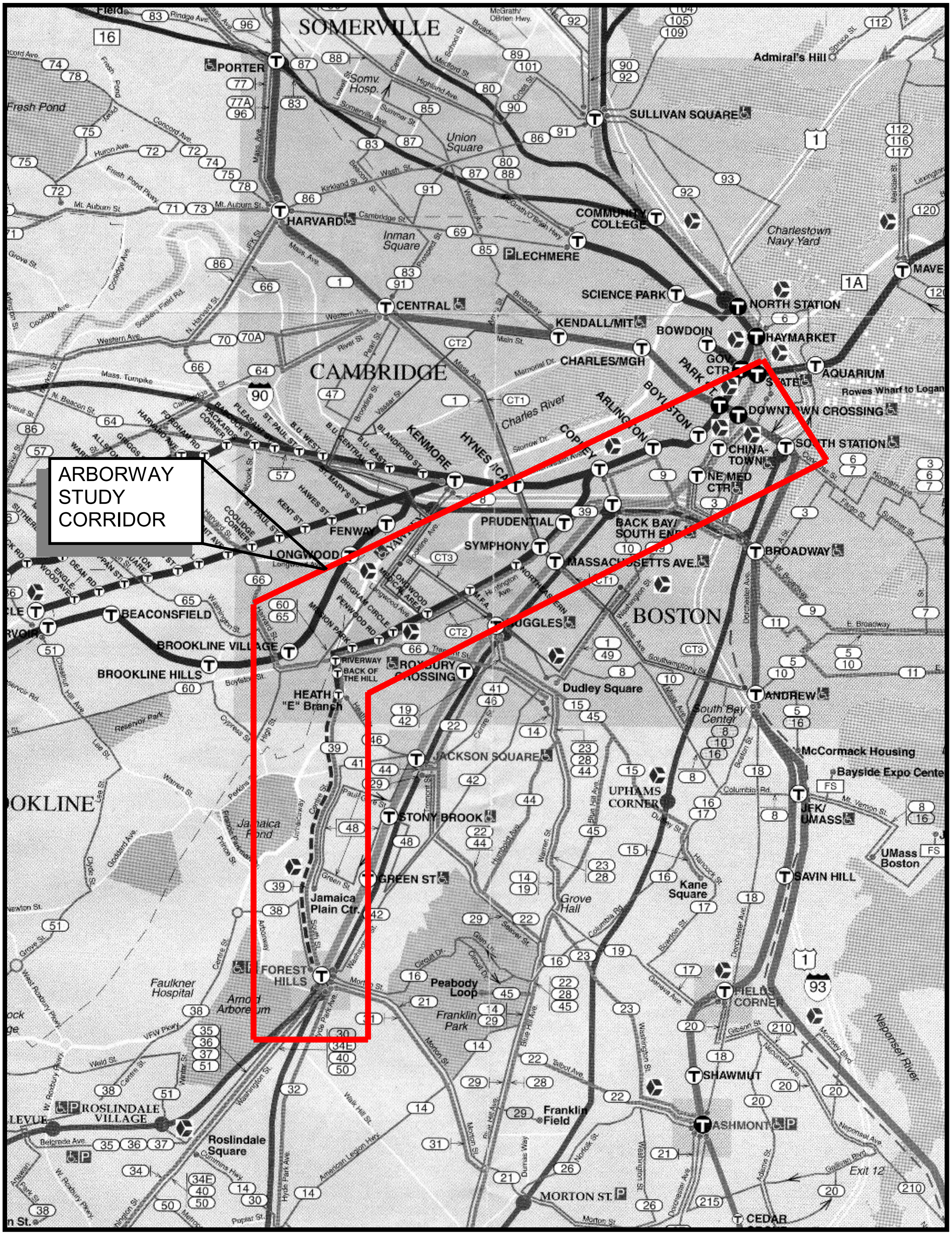
- Starting at the intersection of Arborway and South Street, north along South Street to the intersection of South and Centre Streets.
- From South and Centre Streets north along Centre Street to the intersection of Centre Street and South Huntington Avenue.
- From Centre Street and South Huntington Avenue along South Huntington Avenue to the intersection of South Huntington Avenue and Huntington Avenue.
- From South Huntington Avenue and Huntington Avenue northeast along Huntington Avenue to Copley Square.
- From Copley Square, northeast along Boylston Street to Arlington Street, Beacon Street, Park Street, and terminating at Park Street Station.

The outbound corridor is slightly different north of Huntington Ave:

- From Park Street, south along Tremont Street to Stuart Street, Charles Street, and then Southwest on St. James Street to Huntington Avenue.

The Arborway study corridor contains several significant Boston destinations: Downtown Boston/Park Street Station, the John Hancock and Prudential towers, the Back Bay business district; Northeastern University and the Longwood Medical Area along Huntington Avenue; and the VA Hospital on South Huntington Avenue.

Figure 1
Study Area



2.2 Demographics[1]

The ridership catchment area for the Arborway study corridor is comprised of a variety of distinct areas. The northern portion of the study corridor includes the Back Bay and Copley/Prudential business center. It is bounded by Arlington Street to the northeast and Massachusetts Avenue to the southwest. This area is a regional employment center with almost 76,000 jobs. In addition, more than 24,000 residents live within this area. The Fenway/Medical Complex lies south of this business district, beginning at Massachusetts Avenue and extending south to Heath Street. A more even balance between residents and employees exists within this portion of the study corridor. Almost 31,000 people reside within the area while more than 15,000 are employed there. South of Heath Street and reaching the southern limit of the study corridor below the Arborway/Forest Hills station is the Jamaica Plain area. It is primarily a residential community, with over 29,000 residents and nearly 11,000 employees.

2.3 Street-Level Characteristics[2]

The various roadways comprising the study area have different roadway geometrics, abutting land use, and traffic operating characteristics. Following are descriptions of each roadway and its distinct characteristics.

2.3.1 South Huntington Avenue

South Huntington Avenue extends from Heath Street to Centre Street. This northern section of the study area is the widest, measuring approximately 54' from curb to curb with parking on both sides of the roadway and a 38-foot wide travel lane for two way traffic.

South Huntington Avenue is primarily residential. Housing stock is single family detached two- and three-story homes and several multi-story apartment buildings. The VA Medical Center and Department of Veteran Affairs and other medical treatment centers are located by the Heath Street station and the Massachusetts Society for the Prevention of Cruelty to Animals is located near the Perkins Street intersection.

A traffic signal is located at the South Huntington/Centre Street/Boylston Avenue intersection. Signalized pedestrian crossings are located just south of the Heath Street station, across from the VA Medical Center, and at the intersection with Perkins Street. In addition to the crosswalks located at the two traffic signals, unsignalized pedestrian crosswalks are located at the intersection of Bynner Street.

The bus stops for inbound and outbound service at the Medical Center provide shelters; all other bus stops are without shelter.

South Huntington Avenue was reconstructed in the fall of 2000. Rail from the discontinued light rail service was paved over and the roadway surface is in excellent condition. Based on field observations from 1998, prior to rail removal, people who drove on South Huntington Avenue generally drove between the outside rail and the parked vehicles. However, drivers did travel over the tracks to pass buses pulling over for scheduled stops, vehicles turning right, or vehicles trying to parallel park on the street. With the exception of this passing scenario, adequate width exists such that the dedicated right of way for trolleys does not overlap the dedicated right of way for vehicular traffic.

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[1] 1990 Census (data provided by Central Transportation Planning Staff).
[2] This section includes information from the MBTA report, Analysis of Restoration of Light Rail to the Arborway (URS Corporation Group Consultants, 2001).

Traffic volumes and travel times in the study area were monitored in January 2001. It was observed that in the AM peak hour, traffic volumes were significant heading north on South Huntington Avenue. During the PM peak hour traffic volumes were close to evenly split in both directions. Approximately 13,000 vehicles were recorded using South Huntington Avenue during a 24-hour period.

Trip times were determined by recording the starting time that a vehicle departed a control point at each end of the corridor and when passing other control points in the corridor. South Huntington Avenue between Forest Hills and Heath Street experienced a lower level of congestion than Centre Street and South Street. Less congestion results in faster travel times for automobiles. On average, auto travel times on South Huntington Avenue were under three minutes for the inbound and outbound direction during both peak and off-peak periods.

An inventory of the parking supply in the study area was conducted in December 2000. There are approximately 225 parking spaces on South Huntington Avenue between Heath Street and Centre Street. Between 7:00 and 9:00 AM, 55% of the parking spaces were occupied. This number rose to 68% between 11:00 AM and 2:00 PM and fell to 40% between 4:00 and 6:00 PM. In general, when parking demand is below 85% of the supply, motorists can typically find parking within reasonable walking distance of their destination.

2.3.2 Centre Street

Centre Street extends from South Huntington Avenue to South Street and runs through the center of Jamaica Plain. This street measures approximately 42’ from curb to curb, and approximately 15’ from the curb to the nearest track. A cross-section of Centre Street includes two 8' parking lanes and eight-foot sidewalks on both sides of the roadway and a wide travel lane for vehicles traveling in either the north or south direction. On-street parking is restricted to two hours. The land use on Centre Street is primarily commercial business (restaurants, small clothing stores, food markets, and specialty stores) with some single family and apartment housing.

Traffic signals are located at the intersections of South Huntington Ave with Moraine and Boylston Street, Green Street, and Thomas Street across from the Fire Station. In addition to the crosswalks located at the three traffic signals, unsignalized pedestrian crosswalks are located across Centre Street at Pershing Road, Kingsboro Park, Spring Park, Robinwood Avenue, Beaufort Road, Burrage Street, Grosvenor Street, Greenough Avenue, and Bynner Street.

No shelters are provided along this section of the study area for either inbound or outbound bus service.

On Centre Street the right of way for vehicular traffic overlaps the previous right of way for the trolleys. Vehicles traveling on Centre Street straddle the rails. In general, cars are not parked in the restricted areas for bus stops. In the early afternoon, several school buses also travel on

Centre Street impacting travel times on this section of the study corridor. Left-turning vehicles on Centre Street were not observed as a problem during field visits.

Of all the streets in the Study Area south of Heath Street, Centre Street experienced the highest traffic volumes. Approximately 17,900 vehicles were recorded during a 24-hour period. North of Robinwood Avenue, AM peak traffic volumes were evenly divided between the northbound and southbound. However, during the PM peak, southbound traffic volumes were higher.

On Centre Street north of Harris Street, the primary direction of AM peak traffic is northbound. During the PM peak, traffic volumes are almost equal for both directions.

Travel time data was collected for Centre Street during the AM midday and PM Peak Periods. Inbound vehicles took twice as long to travel Centre Street than South Huntington Street, even though both streets are approximately the same length, because of traffic volumes. This difference is less pronounced in the outbound direction.

There are approximately 215 parking spaces on Centre Street between South Huntington Street and South Street. On-street parking is the primary supply of parking for businesses located in the Jamaica Plain Center. Residential neighborhood areas abut the commercial development in, limiting opportunities for additional parking capacity. No restrictions to on-street parking in these residential areas exists.

Centre Street experiences the highest parking utilization rate, approaching practical capacity of 85% during the midday, in the study area. The parking high utilization rate reflects the commercial character of this portion of the study area. On Centre Street, between 7:00 and 9:00 AM, 77% of the parking spaces were occupied. By midday, 11:00 AM and 2:00 PM, the parking utilization rate rose to 84% of the supply. During the PM peak, the utilization rate decreased to 66%.

2.3.3 South Street

South Street extends from Centre Street to Washington Street at Forest Hills Station. This is the narrowest section of the study corridor between Heath Street and Forest Hills. South Street is similar to Centre Street, measuring approximately 40' from curb to curb, and approximately 15' from the curb to the nearest track. A cross-section of South Street includes 8-foot parking lanes and 8-foot sidewalks on both sides of the roadway and a narrow travel lane for vehicles traveling in either the north or south direction. Portion of on-street parking is restricted to 2 hours.

The major land use on South Street is split between commercial development on the east side of the roadway and single family and apartment housing, primarily on the west side.

Traffic signals are located at Centre Street for pedestrian crossing, and at Carolina Ave, Child Street, McBride Street, and Arborway/New Washington Street by Forest Hills Station. In addition to the crosswalks located at the five traffic signals, an unsignalized pedestrian crosswalk is located at the intersection of Hall Street. The bus stops for inbound and outbound service at Child Street provide shelters; all other bus stops were exposed to the elements.

On South Street the right of way for vehicular traffic overlaps the previous right of way for the trolleys. Vehicles traveling on South Street straddle the abandoned rails In general, cars are not parked in the restricted areas for bus stops. In the early afternoon, several school buses also travel on South Street impacting travel times on this section of the study corridor. The mixed land use (commercial and housing) on South Street is less dense than the primary commercial development located on Centre Street.

Approximately 12,100 vehicles were recorded using South Street during a 24-hour period. During the AM peak period on South Street north of McBride Street, traffic volumes are primarily in the southbound direction. In the PM peak, traffic volumes are nearly equal in both directions.

South Street experienced the longest average auto travel times in the study area. On average, travel time on South Street between Centre Street and Arborway was between seven and eight minutes. However, travel time rises to ten minutes in the northbound direction during the AM peak and southbound in the PM peak.

Parking demand on South Street includes the need for all-day parking by residents. On the section of South Street between Arborway and Child Street, parking demand is near or at 100%. During the AM peak and midday, parking utilization rates remain constant at 73%. In the PM peak, the rate falls to 63% of available parking.

2.3.4 Study Corridor North of Heath Street

South Huntington Avenue extends from Heath Street to Huntington Avenue. South Huntington Avenue measures approximately 54’ from curb to curb. The roadway cross-section includes parking on both sides, a 38-foot wide travel lane for two-way traffic and eight-foot sidewalks along both sides of the roadway. This portion of South Huntington is shared with active Green Line LRV service, with the center of each track located approximately 22 feet from the curb line.

The Huntington Avenue portion of the corridor extends from South Huntington Avenue northerly to Belvidere Street at the Prudential Center complex. The roadway is generally two lanes in each direction with parking and sidewalks on both sides. The travel lanes are separated by the Green Line E branch trolley reservation. The Green Line tracks enter the subway approximately one-half mile south of the Huntington Avenue intersection with Belvidere Street. Signalized intersections are located at South Huntington Avenue, Parker Hill Avenue, Fenwood Road, Tremont Street/Francis Street , Longwood Avenue, Evans Way, Ruggles Street/Louis Prang Road, Parker Street/Forsythe Way, Forsythe Street, Opera Place, Gainsborough Street, Cumberland Street, and Belvidere Street.

Belvidere Street is a two-way roadway with parking that connects Huntington Avenue and Dalton Street.

Dalton Street is a two-way roadway with parking that connects Belvidere Street and Boylston Street. A traffic signal is located at the intersection of Boylston Street.

Boylston Street runs from Dalton Street to Charles Street. It is a three-lane, one-way (eastbound) roadway with parking generally on both sides. Traffic signals are located at the intersections of Gloucester, Fairfield, Exeter, Dartmouth, Clarendon, Berkley, Arlington, Hadassah Way, and Charles Street.

Charles Street extends from Boylston Street to Beacon Street and is a one-way four lane street with parking and sidewalks on both sides. A pedestrian signal is located midway along this link and a traffic signal is located at the intersection of Beacon Street.

Beacon Street extends from Charles Street to Park Street, dividing the Beacon Hill residential neighborhood from the Boston Common. The roadway is two-lane heading west and one lane heading east until Spruce Street, after which it has two lanes heading west and one lane heading east. Parking is provided on both sides. Traffic signals are located at the intersections with Joy Street and Park Street.

Park Street extends from Beacon Street to Tremont Street, also abutting the Boston Common. The street is two-way, with one lane in each direction and parking on one side. There is a traffic signal at the intersection with Tremont. This is the terminal for the proposed bus service. Buses stop and layover on Tremont Street, just south of Park Street.

The outbound trip between the Park Street terminus and Huntington Avenue follows a different route. The various links are as follows:

- Tremont Street extends from Park Street to Stuart Street. This roadway is one-way and typically three to four lanes wide. On-street parking is generally not permitted. Traffic signals are located at the intersections with Winter Street, Temple Place, West Street, Avery Street, Boylston Street and Stuart Street.
- Stuart Street extends from Tremont Street to Charles Street, passing by the State Transportation Building. There are two lanes in each direction with on-street parking. A signal is located at the intersection with Charles Street.
- Charles Street extends from Stuart Street to Park Plaza and is three lanes, one-way with no parking.
- Park Plaza extends from Charles Street to St. James Place. This street is one way and has two travel lanes and parking on both sides. There is a traffic signal at the intersection with Arlington Street.
- St. James Street extends from Park Plaza to Huntington Avenue. This street is one way and has two travel lanes and parking on both sides. There are traffic signals at the intersections with Berkeley Street, Clarendon Street, Dartmouth Street, Exeter Street and Ring Road.

2.4 MBTA Services to the Arborway Study Corridor

2.4.1 Rail Lines

The Arborway study corridor is served by the Green Line's "E" Branch from Heath Street to Copley. Green Line "E" Branch service continues through the Central Subway beyond the study corridor to Lechmere. The Green Line "E" Branch currently operates at 8.5-minute headways during the morning peak. Peak period travel time from Heath Street to Park Street is 21 minutes. There are approximately 14,000 daily boardings at those stations that are exclusively served by the "E" Branch (Heath Street to Prudential).

Customers who use the Route 39 bus (described below) to Copley may transfer to the Green Line for an extra $0.25 fare. According to MBTA statistics, approximately 75% of Route 39 inbound riders have departed the bus by the time it arrives at Copley Station.

The Orange Line operates from the Forest Hills station at the southern end of the study corridor through downtown Boston to the Oak Grove station in Malden. Between 1988 and 1995, an average of almost 12,000 boarded the Orange Line at the Forest Hills station on a daily basis.

2.4.2 Bus Service

Ten bus routes serve the Arborway study corridor between Forest Hills and Park Street: Routes 9, 10, 39, 41, 43, 48, 38, 55, 66 and CT2. Route 39 runs from Forest Hills Station (Orange Line) to the Back Bay/South End Station (Orange Line and Amtrak), approximately 10 miles round trip. During peak periods, the one-way average trip time is approximately 31 minutes. There are approximately 30 stops in each direction along the route. The other bus routes listed above operate along only portions of the study corridor, have significantly lower boardings and much less frequent headways.

2.4.3 Bus Ridership[3]

A recent customer profile indicates a home-based commuter traveling to work on Route 39 at least five days each week. Over 70% of riders live within a five-minute walk to their stops. Route 39 has a large transit-dependent market base: over 40% of riders report that they do not own automobiles, and over 20% report household incomes less than $20,000. A 1995 survey revealed riders to be largely satisfied with Route 39 service: reliability and frequency, which rank as the two most important attributes to customers, were rated above average. However, passenger complaints are received regularly about overcrowding. These complaints reflect to some extent the problem of bus "bunching." Buses tend to bunch, that is, follow closely behind one another, on high frequency, high volume routes with complicating traffic conditions.

The MBTA's 166 bus routes carry over 350,000 passengers during an average weekday. Route 39 is the most heavily used bus route in the system, accounting for nearly 5% of all MBTA bus riders.

2.4.4 Bus Schedule Adherence and Passenger Loads

The schedule adherence of the Arborway study corridor bus routes reflect a number of adverse operating conditions, including high traffic volumes and double-parked cars. Both inbound and outbound trips on Route 39 have typically had maximum loads above MBTA guidelines for at least some portion of the route. Although there is adequate capacity on Route 39, operating issues such as bunching result in uneven loadings at times.

2.4.5 Buses and Garages

All MBTA bus routes are served by 40-foot diesel buses. The MBTA's standard for maximum capacity on these buses is 56 passengers (40 seated). During the weekday AM peak, 23 revenue buses are required for Route 39 service, all of which operate from the Bartlett garage in Roxbury. The Bartlett garage is over 100 years old and is slated for retirement. Buses now operated out of Bartlett will be accommodated elsewhere.

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[3] Sources: MBTA Service Review, Route 39, October 1996 and MBTA 1995 Systemwide Passenger Survey.

3. EVALUATION FRAMEWORK

The framework for evaluating alternatives starts with six basic goals that capture a range of environmental, engineering, and economic considerations and are sensitive to the needs of the Arborway study area:

- Achieve regional air quality standards
- Maintain public safety
- Increase transit usage
- Preserve local business
- Develop an operationally effective solution
- Comply with the Americans with Disabilities Act

A proposed evaluation framework was presented to the public at a meeting in Jamaica Plain on February 28, 2001. The framework was subsequently revised to incorporate suggestions from the community. The full list of goals, objectives and criteria is shown in the table on the next page.

The light rail and CNG bus alternatives are first described in Section 4 and then evaluated in Section 5.

Table 3: Evaluation Framework

Goal	Objective	Criteria
Achieve regional air quality standards	- Comply with Clean Air Act/State Implementation Plan requirements	- Reduce emission of non-methane hydrocarbons, carbon monoxide, and nitrogen oxides
Maintain public safety	- Avoid obstructions to traffic flow	- Allow free passage of emergency vehicles
Increase transit usage	- Increase ridership - One-seat ride to Park Street - Improve schedule reliability - Improve passenger comfort	- Number of riders - Improve passenger waiting areas - Shorten trip time - Reduce crowding and increase number of seats
Preserve local business	- Maintain or improve access to businesses	- Preserve existing on-street parking - Maximize access to businesses by pedestrians, bicyclists, and other traffic
Develop an operationally effective solution	- Maintain overall system performance	- Impact on system reliability - Available maintenance and yard capacity - Compatible with safety goals - Adequate benefit-cost analysis
Comply with the Americans with Disabilities Act	- Ensure service accessibility	- Compliant vehicles, stations, bus stops

4. DESCRIPTION OF ALTERNATIVES

Two alternatives are described in this section in terms of the vehicle that would be used, the operating characteristics of the service, and how the service would be implemented. In Section 5, the alternatives are evaluated against the goals and objectives established for the study.

4.1 Light Rail Alternative

4.1.1 Vehicle characteristics

Two types of light rail vehicles (LRVs) would be operated on this line. The existing Type 7 LRVs, which entered MBTA service in the late 1980's, would be supplemented by the new Type 8 LRVs that are currently being delivered. Both vehicles are 74 feet long, with three doors on each side. A two-car LRV consist would be made up of a Type 7 joined with a Type 8 car to provide accessible LRV service. On a Type 8 car, the front door serves the high floor area and the two central doors access the low floor area of the vehicle. The central doors are accessible to people with disabilities via a bridge plate that is deployed by the train operator. The bridge plate can be deployed 22 inches from the edge of the vehicle and descend six inches to meet the station platform.

4.1.2 Light rail operating characteristics

The light rail service would operate between Forest Hills Station and Park Street. Between Forest Hills and Heath Street, there would be 11 inbound and outbound station stops (not including Heath Street) at the approximate locations shown in the figure on the next page. Final location of the proposed stations is subject to further refinement and input from the community. From Heath Street to Park Street, service would essentially be integrated into the existing "E" Line service.

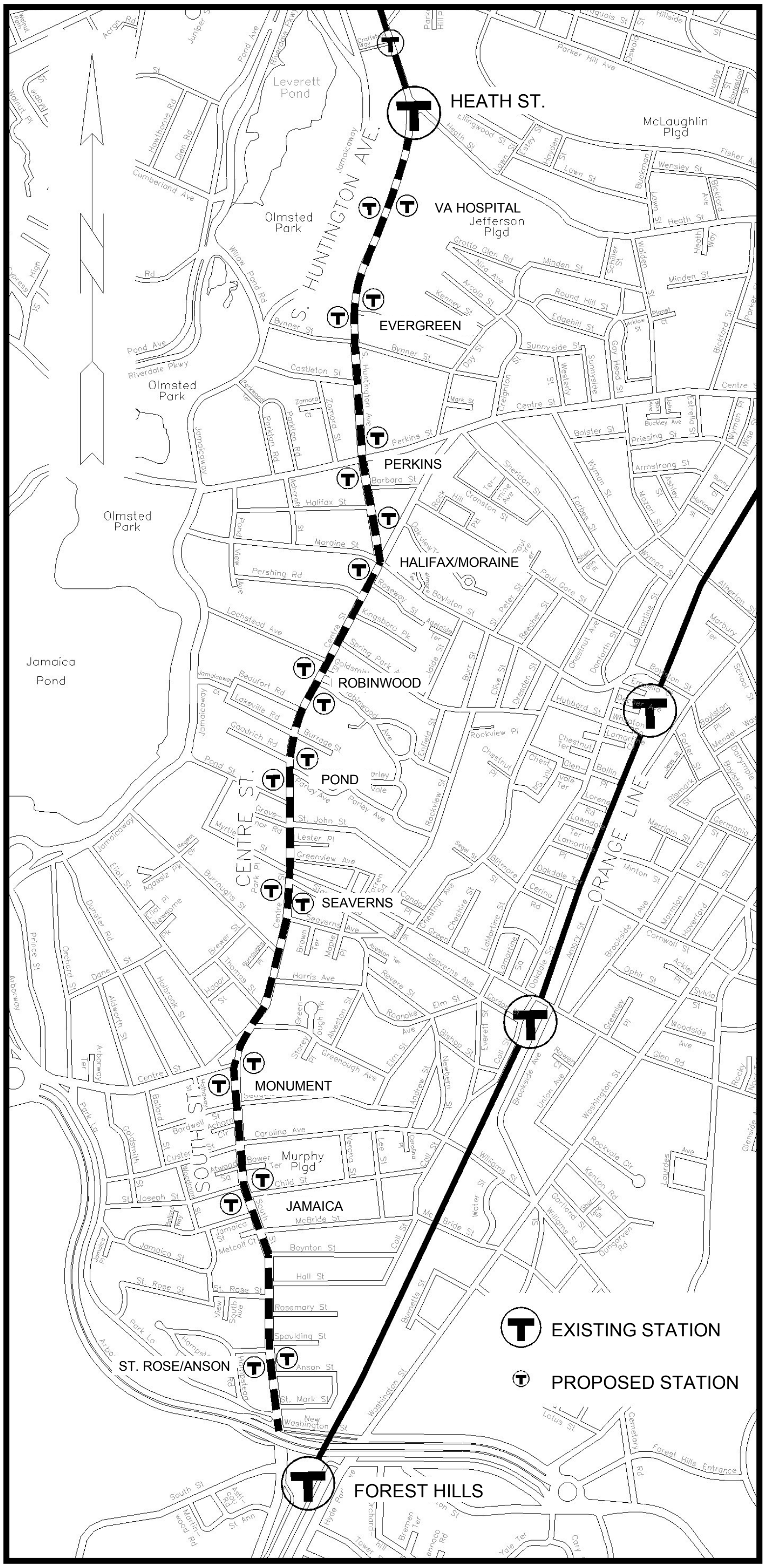
At the recommendation of the DEP, 6-minute headways were assumed for the purpose of this analysis. This represents an increase in frequency over the current 8.5-minute peak headways on the "E" Line. The distances, travel times and numbers of stations are indicated in the table below.

Table 4
Light Rail Service Characteristics

Route Segment (Inbound and Outbound)	Distance (miles)	Travel time (minutes)*	Stations**
Forest Hills to Heath Street	1.9	**13.1**	11
Heath Street to Copley	2.8	16.4	11
Copley to Park Street	0.9	5.3	3
Forest Hills to Park Street	**5.6**	**34.8**	**25**

* Based on average weekday peak trip times.
** Each station includes both an inbound and outbound platform.

Figure 2
Light Rail Route Map



4.1.3 Light rail implementation[4]

Vehicle procurement:

Operation of light rail service between Forest Hills and Park Street will require 16 additional LRVs. This is a result of both increased peak period headways (6-minute versus the current 8.5-minute) and the additional mileage. The LRV requirement was derived by calculating the number of trains required to provide 6-minute peak headways on the "E" Line between Forest Hills and Lechmere (18) and subtracting from that the number of trains currently serving the "E" Line between Heath and Lechmere in the peak (10). The result is a requirement of eight trains, or 16 cars, to provide full "E" Line service.

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[4] Light rail implementation issues are described in more detail in the MBTA report, Analysis of Restoration of Light Rail to the Arborway (URS Corporation Group Consultants, 2001).

Infrastructure requirements:

Light rail service would require track, roadway, power, and utility construction:

- Total reconstruction of track and roadway would be required in order to operate light rail vehicles. Reconstruction of the embedded track and roadway will require careful coordination with the City of Boston's drainage and utility systems. Construction within the roadway right-of-way would likely require replacement of manholes; relocation of existing utilities such as cable, gas, and electric; and drainage improvements.

- The overhead electrical contact system, designed for the older PCC vehicle operations, consists of trolley wires, trolley poles and small duct banks. The existing 2/0 overhead wire and small duct banks cannot carry enough current to operate the proposed two-car LRV consists. Additionally, the traction power system stops approximately 1000' north of Forest Hills Station. Major traction power work will be required to upgrade the system for the current LRV fleet.

- The newer light rail vehicles operate with pantographs rather than trolley poles. Light rail vehicles require 4/0 wire plus messenger overhead, and a duct bank large enough for four positive plus two negative cables. This would require installation of 4/0 wire, messenger wire and a new duct bank between Heath Street and Forest Hills. The current fixed tension system would be replaced with constant tension, similar to the system in place between Brigham Circle and the Heath Street loop. A new electrical sub-station would be required somewhere on this segment of the line. Power would also be required at the Arborway Yard in order to operate cars in the maintenance facility. Poles and wiring would need to be installed at the facility.

  Wayside support poles are located at an average spacing of 75' along the study corridor. These poles have been neglected and several of the foundations are in need of repair. Due to the increased loads which would be carried by the upgraded trolley system, a majority of the poles will need to be replaced and cross spans would be installed. The existing feeder system is located primarily in underground duct banks along the study area. The system will not accommodate the requirements for the restored service and would need to be increased.

Stations:

Light rail service will require 150-foot long platforms to accommodate passenger loading and unloading from two-car train sets, with all doors aligning at the platform. The total space occupied by the station in the street is greater than the length of the station platform (150 feet) by itself. Also included in the overall length are; transition ramps; curb ramps and crosswalks, depending where the station is located on the street. Incorporating the above, island stations have a minimum length of 185 feet and side stations have a minimum length of 200 feet.

Center tracks with side station layouts are proposed for Centre and South Street Stations. Each station is placed on the far side of the intersection to minimize the blocking of the intersection approach while loading and unloading passengers. Each station platform extends out 8 feet from the curb, the width of a normal parking stall and the total length of the station is 200 feet, including platform, transition ramp, curb transition and crosswalks.

Along South Huntington Avenue, either an island platform or side platform could be constructed. Island platforms would extend down the street for 185 feet, including platform, transition ramp and crosswalks. At the station, an 11-foot travel lane is located to the outside of the LRV. Side platforms would be located at the far side of the intersection to minimize the blocking of the intersection approach while loading and unloading passengers. Each station platform extends out 8 feet from the curb, the width of a normal parking stall and the total length of the station is 200 feet, including platform, transition ramp, curb transition and crosswalks. In addition to the new platforms, each station will also be provided with other amenities including a shelter, benches, informational signage, lighting and landscaping.

Maintenance and Storage Requirements:

Implementation of light rail service to Forest Hills would require that a maintenance and storage facility be constructed at the Arborway Maintenance Facility, utilizing approximately an acre of land. The facility would need to be capable of providing vehicle storage, light maintenance and train washing. It is assumed that all other service and maintenance functions could be handled at either Riverside or Reservoir.

Traffic and Parking:

Current traffic congestion is primarily related to activities and traffic volumes on Centre Street, and to a lesser extent South Street, including movements into and out of parking spaces, left turns into side streets, and pedestrian crossings.

Light rail service would change the operating conditions of the corridor. LRVs using the new stations on Centre Street and South Street would stop in the travel lane and stop traffic behind them. Therefore, the speed of traffic directly behind the LRVs will be determined by the LRV operating speeds. Additionally, delays for automobiles and trucks would occur on Centre Street and South Street where it is not possible to pass a transit vehicle at a station. If the LRV travelway is fully or partially blocked by illegally parked vehicles or other obstructions, the LRV and the vehicles behind it will be delayed.

To facilitate LRV accessibility, it is necessary to construct 150-foot long raised platforms at each station stop between Forest Hills and Heath Street. These platforms will essentially be sidewalk extensions; the sidewalk will be extended, or “bulbed out” into the street from the existing curb line. The new platform will in most cases displace existing on-street parking spaces. The loss of parking spaces between Forest Hills and Heath Street is summarized below, and represents a 20 percent net reduction in existing parking along this portion of the corridor. These include both inbound and outbound stops and reflect the net loss, assuming that removal of bus service will actually create new parking.

Table 5
Summary of Light Rail Impacts on Parking

Route Segment	Parking Spaces Lost
South Huntington Avenue	45
Centre Street	45
South Street	30
Total	**120**

The potential for gaining parking spaces between Heath Street and Copley as a result of eliminating Route 39 bus stops was only estimated. This potential gain would not impact businesses and residences between Forest Hills and Heath Street and would not be true replacements for the spaces eliminated between Heath Street and Forest Hills. If all of existing stops north of Heath Street were converted to parking, the gain would be a maximum of 70 spaces. However, since a number of these bus stops coincide with No Parking zones for loading, Fire Department access, and school bus stops, the number spaces that could actually be made available could be up to 50 percent less.

4.2 CNG Bus Alternative

4.2.1 Vehicle characteristics

The bus alternative would utilize 60-foot articulated buses, powered by compressed natural gas (CNG). These buses have a design capacity of 84 (57 seated). The buses would be 100% low floor, facilitating convenient and accessible passenger boarding. Similar to conventional 40-foot buses, the 60-foot buses would have two doors: one by the driver and one in the rear section, behind the articulation. The minimum outside turning radius for the articulated bus is approximately 42 feet, which is slightly better than that of standard buses. However, the inside turning radius may vary by as much as ten feet: while traversing a turn, the longer bus will require approximately ten additional feet of clearance on the inside of the turn.

Natural gas, composed mainly of methane, can be compressed for use as an alternative fuel. CNG-fueled vehicles are being used at approximately 50 transit operations throughout the country, including New York, Miami, Portland, Los Angeles, Fort Worth, Sacramento and Cleveland. The MBTA is planning to operate 60-foot articulated CNG buses on the proposed Washington Street Corridor, known as the Silver Line. The MBTA entered into a contract with Neoplan in October 2000 and the buses are expected to be in operation by the end of 2002.

4.1.4 Operating characteristics

The bus alternative would provide a one-seat ride from Forest Hills to Park Street, as shown in the figure on the next page. Between Forest Hills and Copley Station, the bus would make the stops currently made by Route 39. Between Copley and Park Street, the bus would make the stops currently made by Route 55. (The Arborway service would supplement, not replace Route 55 service.) The service would operate at 4-minute peak headways, the same frequency as current Route 39 service. The total number of stops, travel distances and times are presented in the table below. It should be noted that this is just one option for providing a one-seat ride to Park Street. Additional service planning will be carried out by the MBTA before the actual route is finalized.

Service quality will be substantially improved with the anticipated installation of a Centralized Control System and CAD/AVL (Computer Aided Dispatch/Automatic Vehicle Location) which will enable the MBTA to monitor the exact location of each bus and make adjustments as needed to avoid bus bunching and overcrowding.

Table 6
Bus Route Characteristics

Route Segment	Distance (miles)	Travel time (minutes)***	Bus stops
INBOUND			
Forest Hills to Heath Street	1.9	13.5	**15**
Heath Street to Copley	2.75	17.5	16
Copley to Park Street	1.3	9.5	4 *
Forest Hills to Park Street	5.95	40.5	35 **
OUTBOUND			
Park St. to Prudential	1.5	12	7*
Prudential to Heath St.	2.4	15	13
Heath St. to Forest Hills	2.3	13.5	16
Park St. to Forest Hills	6.2	40.5	36 **

* Stops currently served by Route 55 service.
** Total number of stops represents least-optimized service. Further service planning will be done to optimize travel time and ridership and minimize parking loss.
*** Based on average weekday peak and off-peak trip times obtained from MBTA Ridecheck

4.1.5 Implementation

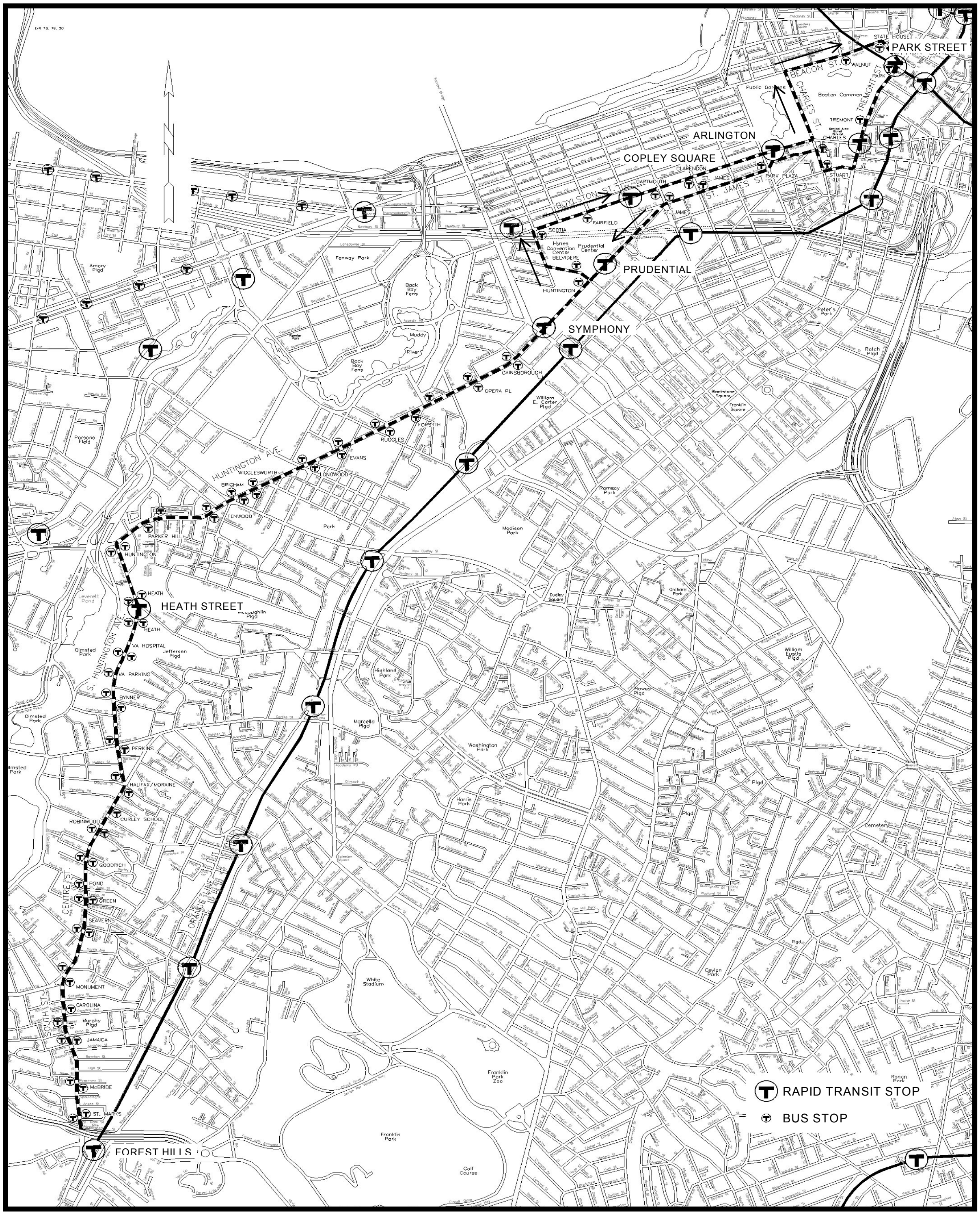
Vehicle procurement:

In order to provide service peak period service to Park Street at 4-minute headways, 26 buses will be required for revenue service.

Infrastructure requirements:

In conjunction with roadway repair by the City of Boston, the tracks and other infrastructure associated with light rail service would be removed.

Figure 3
CNG Bus Service Route Map



Station/Stop Modifications:

To accommodate the longer 60-foot bus at each stop, it will be necessary in most cases to lengthen the current bus stop zone. This may entail eliminating and/or restriping adjacent on-street parking and relocating signs.

Implementation of the bus alternative will also include the provision of amenities such as shelters, benches, information kiosks, route maps and signage at the bus stops. The community could be given an opportunity to influence the design and placement of these features.

Maintenance and Storage Requirements:

The longer, alternatively fueled buses will be stored and serviced at the Southampton Street bus maintenance facility.

Traffic and Parking:

Bus-related traffic congestion is most likely in situations where a bus is not able to pull out of the travel lane into a bus stop because of illegally parked cars. Resolution of this problem is dependent on the City's ability to carry out effective parking rule enforcement. CNG articulated bus service will affect, and be affected by, traffic in the same way as is today's bus service.

Most of the 1.3 miles between Copley and Park Street Stations is along multi-lane one-way roadways, allowing buses to operate around double-parked cars and also allowing traffic to pass buses. However, additional traffic enforcement and supervision may be required along the last quarter-mile of the route that traverses the Boston Common to avoid adverse impacts in this congested area.

Because articulated buses are longer that the buses in service now, bus stop zones will need to be lengthened by at least 20 feet. This enables buses to pull out of the travel lanes and thus minimize impacts to existing traffic. Lengthening bus zones will, in many cases require that adjacent parking spaces be lost or relocated. The loss of parking spaces is summarized below and is based on a detailed field survey of each inbound and outbound bus stop. The number of spaces lost does not directly correspond to the number of bus stops. In many locations, the lengthened stop requirements will have no effect since parking is already prohibited. At other locations, the existing bus stop is already long enough to accommodate longer buses. If bus stops along the route were to be consolidated, the parking loss would be reduced. Further service planning will be undertaken to optimize travel time and ridership and minimize parking loss.

Table 7
Summary of CNG Bus Impacts on Parking

Route Segment	Parking Spaces Lost
Forest Hills-Heath Street	38
Heath Street- Copley Station	18
Copley-Park Street-Huntington Ave	2
Total	58

5. EVALUATION OF ALTERNATIVES

In this section, the light rail and bus alternatives are evaluated in terms of the extent to which they achieve the goals established for Arborway service. Below is a brief discussion of the methodologies used to estimate ridership, emissions levels, and costs. More detailed information is provided in the appendix.

Forecasts of ridership and emissions were produced for each alternative by the Central Transportation Planning Staff (CTPS) to the Boston Metropolitan Planning Organization. The travel model set developed by CTPS is based on a set of computer-based supply and demand models. These models are used to analyze the transportation and air quality impacts of a wide range of highway and transit projects. Typical applications of these models include estimating corridor level ridership on a new or improved transit service, projecting traffic volumes on a new or improved highway facility, analyzing the impact of a service change on the transit system, etc. The model set and its components are of the same type as those used in most large urban areas in North America.

The primary inputs used in the travel model are the study area population, employment, household and socioeconomic characteristics, parking costs, transit fares, automobile operating costs, tolls, and highway and transit levels of service. The model set simulates travel on the entire Eastern Massachusetts transit and highway system. As such, it contains all MBTA rail and bus lines and all private express bus carriers. The model contains service frequency, routing, travel time and fares for all lines. In the highway system, all express highways and principal arterial roadways and many minor arterial and local roadways are included. Results from the computer model provide detailed information relating to transit ridership demand. Estimates of passenger boardings on all the existing and proposed transit lines can be obtained from the model output.

The travel model contains four steps:

1. The total number of trips generated by the households and businesses in the study area is calculated using demographic and socioeconomic data.
2. The trips generated in the first step are distributed throughout the region.
3. The portion of trips that would be made by transit and by auto is determined based on travel times, costs, and other variables such as auto ownership and household size.
4. The trips are assigned to their respective transportation networks, and reports are generated that show transit ridership on different modes and traffic volumes on the highway network.

The amount of pollutants produced under each alternative was estimated using the results from the travel demand model. The mileage associated with each mode was multiplied by mode-specific emissions profiles. Pollutants generated by automobiles, commuter rail locomotives, buses, and commuter boats are included. Pollution generated by the production of electricity that powers the subway and light rail systems are not figured into the calculations.

Capital costs include the purchase of vehicles, infrastructure improvements (such as track, power, stations, bus stops) and maintenance facility requirements. Capital costs do not reflect project management or other costs incidental to construction. Operating costs were developed from an incremental (variable) operating and maintenance cost model. A modified resource build-up approach was used which applies projected unit costs of service to the amount of service that is required for each alternative. Administrative costs are excluded.

Goal: Achieve regional air quality standards

The table below summarizes the emissions associated with the light rail and bus alternatives.

Table 8
Emissions[4A]

Pollutant	Light Rail Alt.	CNG Bus Alt.
Results for the Metropolitan Area Planning Council Region		
Non-Methane Hydrocarbon (NMHC)	**69,449**	69,445
Carbon Monoxide (CO)	**669,221**	669,201
Nitrogen Oxides (NOx)	134,002	134,031
Results for the Arborway Corridor		
NMHC	4,556	4,552
CO	60,759	60,742
NOx	5,755	5,782

Source: CTPS. Pollutant numbers are Kg/day.

The amount of pollutants produced under each alternative was estimated using the results from the travel demand model. The mileage associated with each mode is multiplied by mode-specific emissions profiles. The regional emissions results are very similar for light rail and bus because the alternatives produce very similar numbers of system-wide transit trips. Both the light rail and bus alternative would achieve the emissions reduction targets established for the Arborway restoration project.

Goal: Maintain public safety

In the context of this evaluation, public safety relates to the ability of emergency vehicles to move freely.

As described earlier, light rail service would operate in mixed traffic. Because the Boston Fire Department operates a fire station on Centre Street, the corridor is an important emergency response route. The width of the corridor and the level of traffic and parking activity present challenges for emergency response vehicles using Centre Street and South Street. Observations indicate that the current right-of-way on Centre Street is adequate for vehicles in the travel lane to pull close to the parking lane and create sufficient width in the center of the street for a fire truck or ambulance. However, an LRV in the same circumstance will not be able to move off to the side of the road because it operates in a fixed guideway. This could cause some delay to the emergency vehicles response time as it navigates around the LRV.[5]

CNG buses would be affected by traffic, but they would not have the constraint of a fixed guideway. The driver would be able to move out of the way of an emergency vehicle.

[4A] The air quality estimates for the light rail alternative do not reflect service reductions on the other Green Line branches that would be necessary to accommodate levels of proposed “E” line service.

[5] Letters from the Police and Fire Departments commenting on proposed light rail service are included in Analysis of Restoration of Light Rail to the Arborway, URS Corporation Group Consultants, 2001.

Goal: Increase transit usage

Transit usage is measured by the number of trips that would be made on modes other than automobile. As described earlier, the ridership forecasts produced by the regional travel demand model reflect service characteristics such as directness, trip length, and trip time. In addition, improved schedule reliability, capacity, and passenger comfort are characteristics that would be expected to promote increased transit usage.

The ridership estimated for each alternative is shown in the table below. The first row shows the total number of trips that would be made on all transit modes in the entire metropolitan area under each of the alternatives.

The second row shows the number of transit trips that would be made between Forest Hills and Park Street. The number in the light rail column includes light rail trips only, because under the light rail alternative, bus service would not be provided from Forest Hills. The number in the bus column includes bus trips between Forest Hills and Park Street as well as trips that would be made via the light rail that would continue to exist between Heath Street and Park Street.

Table 9
Average Weekday Ridership[5A]

Catchment Area	Light Rail Alt.	CNG Bus Alt.
Total systemwide linked transit trips (all modes)	811,000	812,200
Total corridor transit trips, Forest Hills – Park Street	34,850 [a]	36,190 [b]

Source: CTPS.

Notes:
[a]: Includes 16,100 light rail trips from Heath Street – Park Street.
[b]: Includes 12,820 light rail trips from Heath Street – Park Street.

With the light rail alternative, there would be approximately 811,000 transit trips in the region. With the bus alternative, there would be approximately 812,200 transit trips in the region. At the regional level, the differences between the alternatives are within the margin of error for the travel demand model. Therefore, the light rail and bus alternatives should be viewed as producing the same number of transit trips and carrying roughly the same level of ridership.

At the corridor level, the differences are more valid and reflect the model's sensitivity to service quantity, frequency, and coverage. Under the light rail alternative, approximately 34,850 transit trips would be made between Forest Hills and Park Street. About 36,190 bus trips would be made between Forest Hills and Park Street. The bus alternative is predicted to have higher transit usage than the light rail alternative primarily because under the bus alternative, two types of transit service are offered: the bus service between Forest Hills and Park Street as well as the existing light rail that would continue to be operated between Heath Street and Park Street.

[5A] The ridership estimates for the light rail alternatives do not reflect service reductions on the other Green Line branches that would be necessary to accommodate levels of proposed "E" line service.

Goal: Preserve local business

Local business is likely to be preserved by maintaining or improving access to the businesses by people and goods arriving by all modes: pedestrian, bicycle, transit, automobile, and truck. Light rail service would have a mixed impact on local business. The connection it would offer to the rest of the MBTA rail network could prompt more people from outside the Arborway area to patronize Arborway businesses. However, light rail service will require a significant reduction in on-street parking. It is estimated that there will be a net reduction of 120 parking spaces between Forest Hills and Heath Street if light rail service is implemented. The net loss reflects the benefits of bus stop consolidation and the existing use of "No Parking" regulations at or near bus stops. Also, light rail service will compete for already limited space on the street. Double parking by trucks is already a concern, because the corridor has few on-street loading zones. Because light rail operates on a fixed guideway, the service will be more sensitive to illegally parked vehicles, inadequate snow removal, and accidents. When such conditions exist in areas where the light rail vehicles cannot be passed, vehicles behind the LRVs would experience delays.[6] These traffic conditions and reduced parking could compromise access to businesses. The construction associated with light rail restoration would also be disruptive to businesses. Construction of track and platforms will result in additional localized traffic congestion and parking loss during the anticipated two-year construction duration.

The CNG bus alternative would pose little adverse impact to local businesses. Traffic would not be expected to be worsened by the change to articulated buses. Construction to remove tracks and other bus-related infrastructure improvements would coincide with roadway repair by the City of Boston. Approximately 38 parking spaces between Forest Hills and Heath Street will need to be eliminated in order to lengthen bus zones for articulated buses.

Goal: Develop an operationally effective solution

Operational effectiveness is evaluated in terms of overall system performance, reliability, and capacity; operating cost; capital cost; and compatibility with safety requirements.

Light rail service from Forest Hills has implications for service on the other Green Line branches. A rail network simulation model was recently developed for the Green Line's Central Subway segment (see Appendix D). This simulation model was used to analyze the capacity impacts that the Arborway restoration project could have on morning peak conditions at Copley Junction, where the "E" Line joins the other three Green Line branches. Copley Junction represents a major pinchpoint during peak operations for two reasons: inbound trains from the Huntington Avenue Line and the Central Subway must converge onto one track; and there is an at-grade diamond crossing of the outbound E track with the inbound track for the other three branches.

As described previously, light rail service from Forest Hills is proposed to have a peak headway of 6 minutes. This would require increased capacity through Copley Junction because the "E" Line peak headway is presently 8.5 minutes. The simulation indicates that because Green Line operations are already at capacity through Copley Junction, additional service on the "E" line would require one-for-one reductions on one of the other three Green Line branches while they are operating two-car trains. If the trains on the Green Line branches were increased to three cars, as is anticipated, each additional “E” line train would require the removal of more than one train on one of the other three branches.[7]

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[6] Analysis of Restoration of Light Rail to the Arborway, URS Corporation Group Consultants, 2001.

Historically, the Green Line has operated with shorter headways. Headways have grown longer over the years for three reasons:

1. Higher capacity rolling stock is now used, which means fewer vehicles (and therefore longer headways) are needed to move the same number of passengers.
2. As longer vehicles have been introduced, the frequency of double-berthing has decreased because of longer train lengths and attendant concerns of passenger inconvenience. (Double-berthing has two trains berthed end-to-end at a station with simultaneous passenger boarding and alighting.) Lack of double-berthing causes train queuing approaching stations and reduces the throughput capabilities of the Green Line.
3. Consistent with national rail transit trends, there has been greater emphasis on slower operating speeds and greater enforcement of posted speed restrictions, which has slowed average speeds and decreased throughput.

Traffic-related obstructions along the Arborway corridor will make it extremely difficult to maintain light rail service with consistent headways. Service to other Green Line branches will be negatively affected if “E” Line trains do not arrive at Copley Junction on schedule.

A storage and light maintenance facility for light rail vehicles will need to be constructed at the Arborway Bus Maintenance Facility site. It is assumed that heavy maintenance would be provided at existing light rail facilities at no additional cost.

Capital and Operating Costs:

The capital cost to restore light rail services estimated to be $76.7 million, as shown below. Given the ridership estimates cited earlier, the capital cost per transit rider at the corridor level is approximately $2,200 for the light rail alternative.

Table 10
Capital Costs to Implement Light Rail Service

Item	Cost
Vehicles	$45.9
Track	13.3
Power	8.5
Stations	1.6
Utilities	2.2
Facility	5.2
Total	**$76.7**

2001 dollars, in millions.

The largest element of the capital cost is the purchase of 16 light rail vehicles. This number was derived by calculating the number of trains required to provide 6-minute peak headways on the “E” Line between Forest Hills and Lechmere (18) and subtracting from that the number of trains currently serving the “E” Line between Heath and Lechmere in the peak (10). The result is a requirement of eight trains (16 cars) to provide full “E” line service. The Arborway service is assumed to have no significant impact on the MBTA’s spare requirements; therefore, capital costs do not include the purchase of spare cars.

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[7] The ridership and air quality estimates for the light rail alternatives presented earlier do not reflect service reductions on the other Green Line branches that would be necessary to accommodate levels of proposed “E” line service.

After an initial investment to restore light rail service, capital outlays would be required in 25 years to replace light rail vehicles at the end of their useful lives and in 30, 40, and 50 years for track, power, and platforms, respectively. The present value of the initial capital outlay plus replacement is $85.1 million, given a discount rate of 5.5% (the MBTA’s cost of capital).

Total operating and maintenance costs for light rail service between Forest Hills and Park Street would be $19.4 million. Today’s costs for providing bus service between Forest Hills and Copley and light rail service between Heath and Park Street are $12.3 million. Therefore, the light rail alternative requires a net increase in operating and maintenance costs of $7.1 million. The methodology for estimating operating and maintenance costs is described in the appendix.

Light rail service would be designed and implemented in a manner that ensures that the service will be operated safely at all times. However, given the constraints of the street, conditions cannot be optimized for all users. For example, at stations, bicyclists will need to maneuver between the 8-inch curb and the outside rail, a distance of approximately 2½ feet. The rail is located in the path of bicyclist and compromises the goal of providing a consistent and uniform riding surface.

CNG bus service would represent an increase in capacity, as the service is proposed as a one-for-one replacement of 40-foot buses with 60-foot, articulated buses. The maximum capacity of a standard bus is 53. Each articulated bus can seat 57 people and accommodate an additional 27 standees. This additional capacity will enable buses to be boarded more easily and as a result, bus stop dwell times and bunching may be reduced.

The CNG buses will be stored and serviced at the Southampton Street bus maintenance facility.

Capital and Operating Costs:

The capital cost to implement CNG bus service is estimated to be $24.7 million, as shown below. The largest element of the capital cost is the purchase of 26 buses. (Spare requirements are assumed to be met on a fleet-wide basis; therefore, capital costs do not include spares.) Given the ridership estimates cited earlier, the capital cost per transit rider at the corridor level is approximately $683 for the CNG bus alternative.

Table 11
Capital Costs to Implement CNG Bus Service

Item	Cost
Vehicles	$17.7
Track	4.2
Power	-
Stations	1.9
Utilities	0.9
Facility	-
Total	**$24.7**

2001 dollars, in millions.

After an initial investment to implement CNG bus service, capital outlays would be required every 12 years to replace CNG buses as they reach the end of their useful lives and in 30 years for roadway and street infrastructure. The present value of the initial outlay plus replacement is $52.5 million, given a discount rate of 5.5% (the MBTA's cost of capital).

The total annual operating costs of CNG bus service between Forest Hills and Park Street would be $8.6 million. Light rail service would continue to be provided at an approximate cost of $8.1 million per year. The total cost of these two services, $16.7 million, represents a net increase of $4.2 million over today's costs for providing bus service between Forest Hills and Copley and light rail service between Heath and Park Street.

Goal: Comply with the Americans with Disabilities Act

Both light rail and CNG bus service will be ADA-compliant. Light rail service will utilize new low floor trains with deployable ramps. Boarding platforms will need to be constructed. CNG buses will be low floor with a deployable ramps. No modifications to the street are required.

Evaluation Summary:

The table on the next page summarizes the comparison of the light rail and CNG bus alternatives. The alternatives produce roughly the same amount of pollutants and are therefore equal in terms of achievement of air quality standards. Under each alternative, total systemwide linked transit trips are about equal, with the light rail alternative associated with 811,000 regional transit trips and the CNG bus alternative associated with 812,200 regional transit trips. Neither of these represents a statistically significant increase in transit trips. The corridor ridership associated with the light rail alternative (34,850) would be slightly lower than that of the CNG bus alternative (36,190). The capital cost per transit rider at the corridor level is $2,200 for the light rail alternative and $683 for the CNG bus alternative.

The alternatives differ most significantly in terms of the characteristics that affect access to businesses, public safety, and operational effectiveness. The light rail alternative will adversely affect the character and use of the street during construction and after implementation. The CNG bus service does not have these impacts. Light rail service creates capacity issues: because Green Line operations are at capacity through Copley Junction, additional service on the "E" Branch competes with service on the other Green Line branches. CNG bus service creates additional capacity by substituting higher-capacity articulated buses for lower-capacity standard buses.

Table 12
Evaluation Summary

Goals and Objectives	Criteria	Light Rail Alt.	CNG Bus Alt.
Achieve regional air quality standards	NMHC		
	- Region	69,449 Kg/day	69,445 Kg/day
	- Corridor	4,556 Kg/day	4,552 Kg/day
	Nitrogen Oxide		
	- Region	134,002 Kg/day	134,031 Kg/day
	- Corridor	5,755 Kg/day	5,782 Kg/day
	Carbon Monoxide		
	- Region	669,221 Kg/day	669,201 Kg/day
	- Corridor	60,759 Kg/day	60,742 Kg/day
Increase transit usage	Total systemwide linked transit trips	811,000	812,200
	Corridor transit trips	34,850	36,190
Maintain public safety	Barriers to free passage of emergency vehicles	Barriers exist	No barriers
Preserve local business	Traffic impacts due to construction?	Significant	Minor
	Reduction in on-street parking.	120 spaces	58 spaces
Develop an operationally effective solution	Capital cost	$76.7 million	$24.7million
	O&M cost for all transit between Forest Hills and Park Street	$19.4 million	$16.7 million
	Net increase in operating cost over current Route 39 service	$7.1 million	$4.2 million
	Available operating capacity?	Requires reductions in other Green Line service	Yes
	Available maintenance and yard capacity?	Modifications required	Yes
Comply with ADA	Impacts to achieve compliance with Americans with Disabilities Act	Significant	Minor

APPENDIX A:

CAPITAL COSTS

COST SUMMARY

Total capital costs are the sum of costs for vehicles, infrastructure and maintenance facilities, as summarized in the table below. All costs are presented in 2001 dollars.

Table 1: Summary of Capital Costs

Item	LRV Alternative	Artic. CNG Alternative
Vehicles	$45.9	$17.7
Track	13.3	4.2
Power	8.5	-
Stations	1.6	1.9
Utilities	2.2	0.9
Facility	5.2	-
Total	**$76.7**	**$24.7**

(Millions of 2001 dollars)

Vehicle Costs

Total vehicle cost is derived by multiplying the number of vehicles required by a unit price. The number of vehicles reflects peak requirements (a function of headways, cycle time and recovery time). A total of 16 LRVs or 26 articulated CNG buses are required. Unit costs are listed below.

Table 2: Vehicle Unit Prices

Alternative	Unit Cost	Source/Derivation
LRV	$2,870,000	MBTA forecast
Artic. CNG	$682,000	MBTA forecast

Infrastructure Costs

Infrastructure costs include costs for track, power, stations/stops and utilities. The track cost for the bus alternative represents removal of existing rail.

Table 3: Roadway Reconstruction Costs – Bus Alternative*

Item	Quantity	Unit	Cost/Unit	Cost
Track removal and disposal	15,400	CY	$174	$2,674,000
Pavement replacement	23,200	TF	20	457,000
			Subtotal	$3,131,400
			+ 35% Contingency	1,096,600
			Total	**$4,227,000**

Table 4: Track Replacement & Relocation Costs – LRV Alternative[*]

Item	Quantity	Unit	Cost/Unit	Cost
Track removal and disposal	20,000	CY	$174	$3,480,000
Pavement Replacement	9,800	CY	191	1,872,000
New Track	24,300	TF	185	4,496,000
			Subtotal	$9,848,000
			+ 35% Contingency	3,447,000
			Total	**$13,295,000**

Table 5: Traction Power Costs*

Item	Quantity	Unit	Cost/Unit	Cost
Traction power	24,300	TY	$260	$6,318,000
			+ 35% Contingency	2,211,000
			Total	**$8,529,000**

Utilities
Utilities costs are assumed to be equal to 15% of the cost of track and stations.

Stations
Station costs capture costs associated with trolley plazas. The tables below summarize these costs. The estimates are based on a total of 11 new LRV stations between Forest Hills and Heath Street. (Estimate does not include Heath Street).

Table 6: LRV Station Costs*

Item	Cost
Platforms (150' long, 8' wide, Bit. Conc.)	$65,000
Granite Curb	146,000
Tactile Surface Pavers	42,000
Shelters	637,000
Benches	42,000
Signage	69,000
Lighting	139,000
Trash Receptacles	14,000
Subtotal	*$1,154,000*
+ 35% Contingency	*404,000*
Total	**$1,558,000**

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[*] These estimates exclude maintenance and protection of traffic, utility relocations, right-of-way acquisition, and roadway improvements as part of work by others. This estimate is order-of-magnitude, for comparative purposes. It is recommended that a detailed inspection and design be performed.

Bus stop amenities costs are based on bus stop improvements at 31 existing Route 39 bus stops between Forest Hills and Heath Street.

Table 7: Capital Cost for Bus Stop Amenities[*]

Item	Cost
Site & Concrete Work	$12,000
Shelter	25,000
Kiosk	8,000
Benches	6,000
Lighting/Public Telephone	6,000
Route Map/Signage	6,000
Subtotal	$63,000
x Number of Stops	x 31
Total	**$1,950,000**

Facility Costs

Because the maintenance of the CNG buses will be handled at the Southhampton Street maintenance facility, the bus alternative does not have incremental facility costs. Facility costs for light rail restoration are described below.

Assuming that light rail vehicles would be stored and cleaned at the Arborway Facility but maintained elsewhere, modifications to the scope and cost of the planned facility are as follows:

Table 8: Facility Costs for Light Rail Restoration

Item	Cost
Construct traction power system, including substation, switchgear, catenary structures and wire, relative to yard and facility.	$2,300,000
Construct 3 outdoor yard storage and circulation tracks, and lead track to main line.	2,300,000
Construct a basic exterior car wash system and support facility for equipment (approx. 1,000 sq. ft.).	580,000
Add’l cash vaulting station for light rail vehicles.	$60,000
Total	**$5,240,000**

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[*] These estimates exclude maintenance and protection of traffic, utility relocations, right-of-way acquisition, and roadway improvements as part of work by others. This estimate is order-of-magnitude, for comparative purposes. It is recommended that a detailed inspection and design be performed.

APPENDIX B:

OPERATING AND MAINTENANCE (O&M) COSTS

OPERATING AND MAINTENANCE COST MODEL DEVELOPMENT

An incremental (variable) operating and maintenance (O&M) cost model was developed that applies projected unit costs of service to the amount of service that is required for each alternative. The O&M unit costs were derived utilizing the FY 2000 MBTA National Transit Database Section 15 reports. Section 15 reports provide detailed annual costs by mode for Vehicle Operations, Vehicle Maintenance, Non-Vehicle Maintenance, and Administration. Each of these categories is further broken out into:

- Labor
- Fringe benefits
- Services
- Materials and Supplies (including fuel, lubricants, tires, and other supplies)
- Utilities
- Casualty/Liability
- Taxes
- Purchased Transportation
- Miscellaneous Expenses
- Expense Transfers

The incremental cost model used in this study assumes that the costs associated with each of these sub-categories depend on Revenue Hours, Revenue Miles or Peak Vehicles. The following description of the assumptions made in this O&M cost model applies to all of the alternatives except where noted.

- Labor, Fringe Benefits, Services, and Miscellaneous Expense costs were assumed to depend on Revenue Hours. This dependency implies that the hours of vehicle operation drive the labor and benefit costs. The Materials and Supplies costs were assumed to depend on Revenue Miles. This dependency implies that the distance vehicles travel determines how much fuel they use and how much they wear their tires. There were no Casualty/Liability, Tax, Purchased Transportation, or Expense Transfer costs associated with Vehicle Operations.

- All costs associated with Vehicle Maintenance were assumed to depend on the number of Peak Vehicles. This was based on the assumption that maintenance costs are a function of the number of vehicles required.

- All costs associated with Non-Vehicle Maintenance for the bus alternative were assumed to depend on the number of Peak Vehicles. Non-Vehicle maintenance includes such costs as upkeep of maintenance facilities. This O&M model assumes that as a vehicle fleet increases (i.e., as Peak Vehicles increases), the costs associated with facilities increase proportionally. In the case of light rail, the costs associated with Non-Vehicle Maintenance were assumed to depend on the length of Track Miles. This differentiation was based on the additional need to maintain the right-of-way.

- Administrative costs are excluded from this analysis; that is, they are expected to be stable from one alternative to another.

- Because articulated CNG buses are not currently operated by the MBTA, costs for this mode were estimated by adjusting MBTA costs for standard diesel buses as described below.

  Factors used to convert the costs of a diesel bus to a CNG bus were derived using information from the MBTA's April 2000 Prototype Evaluation of New Technology Buses. According to the MBTA's 2000 New Technology Buses Study, the fuel cost per mile of operation for a standard diesel bus is $0.15. For a standard CNG bus the fuel cost per mile is $0.30. This 100% increase in fuel related costs was used to factor the CNG alternatives. Also according to the New Technology Buses Study, the maintenance and facilities costs per mile of operation for standard diesel buses are $0.34. For standard CNG buses these costs are $0.66. This 94% increase in maintenance and facilities costs was used to factor the CNG alternatives.

  Factors used to convert costs from standard 40' buses to articulated buses were made based on previous work by SYSTRA in San Diego and New Jersey. Fuel related costs for articulated vehicles were assumed to be 60% greater than fuel costs for 40' buses. Similarly, maintenance costs for articulated vehicles were assumed to be 25% higher for articulated buses versus standard 40' buses.

CALCULATION OF O&M COSTS FOR EACH ALTERNATIVE

The modeled unit costs were multiplied by the operating statistics associated with each alternative to calculate total costs, as summarized in the table below.

VARIABLE (INCREMENTAL) OPERATING & MAINTENANCE COST SUMMARY

	Annual Variable	Unit Cost	Total Annual Cost 2000$
Light Rail Alternative	125,078 Revenue Car Hours	$125.51 /Revenue Train Hour	$15,698,657
	1,055,933 Revenue Vehicle Miles	$0.76 /Revenue Vehicle Mile	802,294
	16 Peak Vehicles	$102,564 /Peak Vehicle	1,641,020
	5.6 Track Miles	$219,759 /Track Mile	1,230,649
Total O&M Cost			**$19,372,621**
Articulated CNG Bus	73,691 Revenue Vehicle Hours	$54.81 /Revenue Vehicle Hour	$4,039,083
	617,061 Revenue Vehicle Miles	$0.69 /Revenue Vehicle Mile	428,482
	26 Peak Vehicles	$158,810 /Peak Vehicle	4,129,064
Total O&M Cost			**$8,596,628**

APPENDIX C:

RIDERSHIP AND AIR QUALITY FORECASTS

CTPS CENTRAL TRANSPORTATION PLANNING STAFF

Staff to the Boston Metropolitan Planning Organization

MEMORANDUM

TO: **Monica Barrow, Systra Consulting Inc.** **May 16, 2001**

FROM: **Vijay Mahal**

RE: **Ridership Analysis for the Arborway Study**

1.0 Introduction/Summary

Transit ridership for two Arborway alternatives was estimated using the CTPS travel demand model. The first alternative, hereafter referred to as the "bus alternative", involves running a compressed natural gas (CNG) bus from Forest Hills to Park Street. The second alternative, known as the LRT extension involves extending the current E-branch of the Green Line from Heath Street to Forest Hills along South Huntington and Center streets.

Our model results indicate that in general, the transit ridership in the Arborway corridor would be approximately the same under both the LRT and the bus alternatives. However under the LRT alternative, the results indicate it is likely that a small portion of the transit trips will be lost to the auto mode. This is primarily due to the elimination of Route 39 service in this alternative which currently is one of the highest ridership carrying routes in the MBTA system. The air quality analysis indicates that both the LRT and bus alternatives would achieve a reduction in air pollution in the study area when compared to the 1991 SIP base case assumptions.

The remainder of this memorandum will describe the CTPS travel model, major assumptions used in the alternatives and discuss the ridership results in detail.

2.0 The CTPS Travel Model

The travel model set developed by CTPS is based on a set of computer-based supply and demand models. This model set has been used extensively over the past several years for a wide variety of projects such as the South Boston Piers Transitway, the Urban Ring Study, the Worcester Commuter Rail Extension Study, the Rail Link Study etc. The model set and its components are of the same type as those used in most large urban areas in North America.

The primary inputs used in the model are the study area population, employment, household and socioeconomic characteristics, parking costs , transit fares, automobile operating costs, tolls and highway and transit levels of service. The model set simulates travel on the entire Eastern Massachusetts transit and highway system. As such, it contains all MBTA rail and bus lines and all private express bus carriers. The model contains service frequency (i.e. how often trains and buses arrive at any given transit stop), routing, travel time and fares for all these lines. In the highway system, all express highways and principle arterial roadways and many minor arterial and local roadways are included. Results from the computer model provide us with detailed information relating to transit ridership demand. Estimates of passenger boardings on all the existing and proposed transit lines can be obtained from the model output.

The model contains four important steps.

In the first step, the total number of trips generated by the residents of the eastern Massachusetts area is calculated using demographic and socioeconomic data. Similarly, the number of trips generated by different types of land use such as employment centers, schools, hospitals, shopping centers etc., are estimated using demographic, socioeconomic and land use data. This information is produced at a highly disaggregated geographic area known as traffic analysis zones (TAZ). In our model, there are 873 TAZs that cover 164 towns and cities in the eastern Massachusetts area. All calculations are performed at the TAZ level.

In the second step, the model determines how the trips generated in the first step would be distributed throughout the region. To do this, the model considers the transit and highway travel times between TAZs and the relative attractiveness of each TAZ which is influenced by the number of jobs available, size of schools, hospitals, shopping centers etc.

Once the total number of trips between all possible TAZs is determined, the model proceeds to the third step where it calculates the portion of the total trips that would use the transit system and those that will be made by the auto mode. To determine this proportion, the model takes into account the travel times, number of transfers required and costs associated with the transit and auto options. Other variables such as the auto ownership and household size are also included in the model.

Once the number of transit and auto trips is estimated for all possible TAZ combinations, the model proceeds to assign them to their respective transportation networks (this is the fourth and final step). After the traffic assignment is completed, the model generates various reports showing the transit ridership on different modes and traffic volumes on the highway network.

Prior to running the model set, market areas are delineated for all the transit stops and rail stations of the entire MBTA system. These are the geographic areas from which most users of each transit stop and rail station would likely come. They are delineated on the basis of detailed information collected from our periodic commuter rail surveys, bus passenger surveys, the Journey-to-Work data, existing travel characteristics and expected future transit service configuration in all corridors of the metropolitan region.

For this project, the model set was run and adjusted several times until it replicated the existing highway and transit counts at an acceptable level of accuracy within the study area. Then the calibrated model was applied to test new transit alternatives.

3.0 Transit Alternatives Analyzed

3.1 Bus Alternatives

Alternative 1

This alternative involves running a 60-foot, articulated CNG bus from Forest Hills to Park Street. The proposed route would follow the existing Route 39 bus to Copley, then follow Route 55 to Park and Tremont streets. Headways on this new route would be maintained at the same level as the current route 39 bus. The stops on this route would be similar to Route 39 and Route 55. The current Route 55 would be retained in this alternative. Passengers would enjoy markedly better service (more seats at the same headways with a new one-seat ride to downtown). Figure 1 shows the routing of this alternative.

Alternative 2

This alternative is identical to Alternative 1 except the headway on the new route would be 6 minutes.

3.2 LRT Extension

This alternative involves extending the LRT from its current Heath Street terminal to Forest Hills. The proposed stops on the LRT extension are shown in Figure 2. The proposed headway for this alternative is 6 minutes, which represents an improvement from the current 8-minute headway for the section between Heath Street and Lechmere. Under this alternative, the current Route 39 bus would be eliminated altogether. The LRT portion between Heath Street and Forest Hills would be operating in the mixed right-of-way and therefore would be subjected to the same traffic congestion as the regular traffic.

Figure 1 Proposed Routing of the Bus Alternative

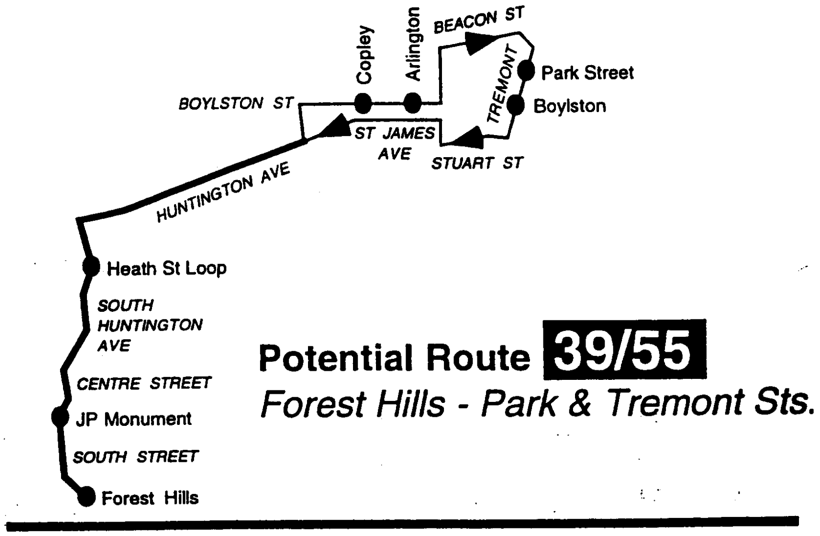
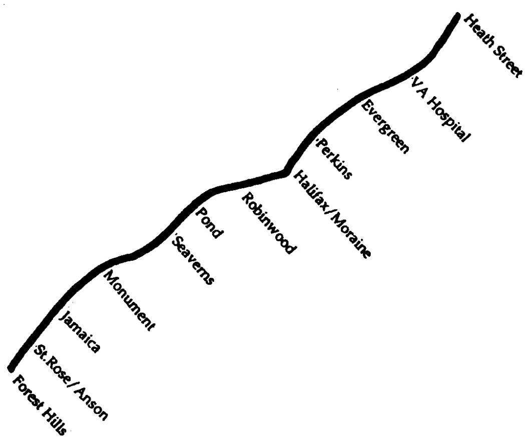


Figure 2 Proposed Stops on the LRT Extension



3.3 *Level-of-service Assumptions*

Shown below in Table 1 are the service assumptions used in the analysis.

Table 1. Service Characteristics of the Arborway Alternatives

	Current Route 39 Bus Headway = 3 to 4 min Fare=75 Cents			Bus to Park Street Headway= 3 to 4 min Fare= 75 Cents			LRT extension Headway=6 min Fare= $ 1.00		
	Travel time (min)	Travel distance (miles)	Speed (MPH)	Travel time (min)	Travel distance (miles)	Speed (MPH)	Travel time (min)	Travel distance (miles)	Speed (MPH)
Forest Hills to Heath Street	13.5	1.9		13.5	1.9		13.1	1.9	
Heath Street to Copley	17.5	2.75		17.5	2.75		16.4	2.77	
Copley to Park	n/a	n/a		9.5	1.3		5.3	0.93	
Total	31	4.65	9.00 MPH	40.5	5.95	8.8 MPH	34.8	5.6	9.66 MPH

4.0 Discussion of Ridership Results

The ridership results of the travel model are summarized in Table 2. Shown in columns are the results of different transit alternatives. For the purposes of comparison, the alternative representing the 1991 base case assumptions is also presented. The number shown in the first row of Table 2 is the total number of linked transit trips made in the entire region under each alternative. Higher this number, the better the alternative is in terms of its ability to attract new transit riders from other modes such as the automobile.

The estimated transit ridership for each alternative is shown in the second block of Table 2. Ridership is reported for different segments of the Arborway corridor for easy comparison. The last block of Table 2 contains the results of the air quality analysis and the change in vehicle miles traveled on the highway system.

As seen from the table, under the bus alternative (Alt 1), there would be roughly 812,200 transit trips made in the region which is about 650 more trips than the No-Build case. In other words, this alternative diverts approximately 650 trips from the auto mode to the transit mode. As noted earlier, this alternative would

Table 2. Results of the Ridership and Air Quality Analysis

Base Year 2000 Simulation

	1991 SIP Base Case (1987 Study assumptions) Rte 39 Diesel Bus @H=7 min	No Build (1999 Study) Rte 39 Diesel Bus @H=4 min	Alternative 1 CNG Bus to Park Street @H=4 min	Alternative 2 CNG Bus to Park Street @H=6 min	Alternative 3 LRT Extension @H=6 minutes
Total System wide Linked Transit Trips	*810,650*	*811,550*	*812,200*	*811,400*	*811,000*
Arborway Corridor Ridership (up to Park Street)	*30,600*	33,690	36,190	33,335	34,850
Air Quality Results (within MAPC) All emissions are in Kg/day					
VOC	*not available*	72,119	72,148	72,149	72,118
Nox	141,565	134,020	134,031	134,033	134,002
CO	974,989	669,224	669,201	669,226	669,221
NMHC	74,372	69,450	69,445	69,449	69,449
PM	32,074	32,072	32,070	32,072	32,073
Air Quality Results (within the Arborway Corridor study area) All emissions are in Kg/day					
VOC	*not available*	5,912.60	5,940.60	5,937.80	5,911.60
Nox	*not available*	5,772.80	5,782.30	5,784.00	5,755.40
CO	*not available*	60,761.80	60,742.60	60,759.40	60,759.20
NMHC	*not available*	4556.51	4552.27	4555.82	4556.05
Increase/Decrease in VMT with respect to 1991 SIP		-3,780	-6,495	-3,135	-1,430
Increase/decrease in Linked transit trips with respect to No-Build			650	-150	-550

provide a convenient, highly frequent, one-seat ride from Forest Hills to downtown. Since the LRT service from Heath Street to Lechmere still exists in this alternative, the new bus alternative represents an increase in overall service in the Arborway corridor. This is the main reason for the overall increase in systemwide linked transit trips. The new bus alternative is expected to carry about 23,370 riders a day. The total ridership (bus and LRT included) in the Arborway corridor (Forest Hills to Park Street) is estimated to be 36,190 trips per day under this alternative.

Alternative 2 is the same bus alternative analyzed in Alternative 1 but the headway is changed from 4 minutes to 6 minutes. The revised headway represents a degradation in service when compared to the No-Build alternative. As a result, the ridership drops to 18,760 trips per day inspite of the fact that this alternative provides a one-seat ride to downtown. In general, passengers are very sensitive to service frequency and our models are designed to capture that sensitivity.

Alternative 3 will eliminate the current Route 39 bus service and restore the LRT service from Heath Street to Forest Hills. The current Route 39 runs on a 3 to 4-minute headway during the peak period, provides several convenient stops for an affordable fare. Eliminating this service altogether has an adverse impact on the overall corridor ridership. Though the LRT service represents an improvement from the current conditions (6-minute headway compared to existing 8-minute headway), the overall level-of-service in the Copley to Forest Hills segment is greatly reduced due to the elimination of Route 39. This action results in a reduction of systemwide linked transit trips. As seen from the table, the LRT alternative would actually lose a small number of transit trips to the auto mode when compared to the No-Build case. However, these reductions are so small, one can consider them to be within the margin of error of the model. It should be pointed out that due to the capacity constraints in the central subway system, providing a 6-minute service on the E-Line would mean reducing service on the other branches of the Green Line. In the current analysis however, we did not assume any service reduction on the other branches of the Green Line. Therefore, the ridership and air quality estimates for the LRT alternative represent a more optimistic operational condition on the Green Line branches.

In general, the margin of error associated with travel demand models range between 5 and 10 percent. Even the best calibrated models have a margin of error of at least 5 percent. So, for all practical purposes, we must conclude that all these three alternatives produce approximately the same number of transit trips and carry roughly the same level of transit ridership.

5.0 Air Quality Analysis

The amount of gaseous pollutants produced under each alternative was estimated using the travel demand model. Pollutants generated by the automobile traffic, commuter rail locomotives, buses and commuter boats are included in the analysis. However, the pollution generated by the production of electricity that runs the LRT and the subway system is not figured in the calculation. As shown in Table 2, all alternatives including the No-Build has a better air quality impact than the 1991 SIP base case assumptions.

The difference in air quality impacts between the LRT and bus alternatives is well within the margin of error of the model. For example, the increase in pollution for the bus alternative when compared to the LRT alternative represents only 0.004 percent of the total pollution in the study corridor. At the regional level, this increase represents even a smaller number, in the order of 0.0004 percent. Therefore, for all practical purposes, we must conclude the air quality impact of both the LRT and bus alternatives is a statistical tie.

APPENDIX D:

RAIL NETWORK SIMULATION MODEL TECHNICAL MEMORANDUM

Introduction

Under contract to the Massachusetts Bay Transportation Authority (MBTA), SYSTRA Consulting, Inc. developed a rail network simulation model of the MBTA's future operations for the Green Line's Central Subway segment. The Green Line is actually a complex light rail network that consists of four branches that converge into one line within the Central Subway system, bringing thousands of commuters into downtown Boston daily.

The Arborway project is a study of renewing service on the MBTA Green Line's "E" Line between Heath Street and Arborway. This former segment of the "E" Line, taken out of service in the 1980's, was a mixed traffic light rail operation. The outer portion of the "E" Line, terminating at Arborway, was plagued by traffic congestion and slow speeds, as well as safety concerns. "E" Line service was cut back to Heath Street, its current terminus, with the remaining part of the line served by frequent bus service.

Methodology

SYSTRA's task in this simulation is to analyze the capacity impacts that the renewed service could have on the entire Green Line, specifically morning peak conditions at Copley Junction, where the "E" Line joins the other three Green Line branches. Copley Junction represents a major pinchpoint in peak operations, not only because inbound trains from the Huntington Avenue Line and Central Subway must converge onto one track, but because there is an at grade diamond crossing of the outbound E track with the inbound track for the other three branches. Because the current Green Line operating plan results in frequent congestion in tunnel portions such as Copley Junction, changes in service patterns must be carefully analyzed from the point of view of passenger throughput. The table below summarizes the characteristics of Green Line service as it is currently operated:

Existing Green Line Service Characteristics

		WEEKDAY															WEEKEND					
Rte.		A.M. PEAK			A.M. BASE			P.M. BASE			P.M. PEAK			LATE			SAT PEAK			SUN PEAK		
No.	Terminals	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.
	LIGHT RAIL DIVISION																					
	RESERVOIR STATION																					
812	Boston College -Government Ctr. Sta.	22	2	5	12	2	8	12	2	8.5	21	2	5	11	1	10	15	2	7	18	1	5
832	Cleveland Circle - Government Ctr. Sta.	13	2	6.5	13	1	6	13	1	6	13	2	6.5	7	1	10	16	1	5	11	1	7
850	Riverside - Lechmere Sta.	26	2	4.5	12	2	10	12	2	10	27	2	4.5	11	1	10	20	1	6	18	1	7
880	Heath Sta. - Lechmere Sta.	10	2	8.5	8	2	9	8	2	9	10	2	8.5	8	1	10	10	2	7	14	1	5
RAD	Boston College										1	2	X	1	1	X				1	1	X
RAD	Lechmere																					
RAD	Riverside	1	2	X							1	2	X				2	1	X	2	1	X
RAD	Cleveland Circle	2	2	X							1	2	X	1	1	X	2	1	X	1	1	X
	TOTAL CARS:	148			77			77			148			39			90			64		

NOTES:

V = VEHICLES
C = CARS PER TRAIN
H = HEADWAY
X = IRREGULAR HEADWAY
RAD = RUN AS DIRECTED

After simulating current Green Line operations using the RAILSIM® Simulation Software Suite, the maximum hourly throughput at Copley Junction in the morning was 93 trains per hour, or 44 eastbound trains and 49 westbound trains. The actual hour of peak throughput occurred between 8:27 and 9:27 AM. This somewhat later than the traditional morning peak, but reflects the "flat" nature of the MBTA service plan over the extended peak and the fact that shorter dwells after the peak ridership subsides support higher throughput.

For the purposes of this simulation, a 30% increase in morning peak hour service frequency was used, reducing the current peak hour headway on the “E” Line from 8.5 minutes to 6 minutes. The scheduled frequency was thus increased from 7.1 to 9.2 trains per hour per direction, an increase of about two trains each direction per hour. The table below outlines the operating characteristics of all four Green Line branches with this increased morning peak frequency for the “E” Line:

6. SERVICE PLAN WITH ADDED AM PEAK “E” LINE SERVICE

		WEEKDAY															WEEKEND					
Rte.		A.M. PEAK			A.M. BASE			P.M. BASE			P.M. PEAK			LATE			SAT PEAK			SUN PEAK		
No.	Terminals	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.
	LIGHT RAIL DIVISION																					
	RESERVOIR STATION																					
812	Boston College -Government Ctr. Sta.	22	2	5	12	2	8	12	2	8.5	21	2	5	11	1	10	15	2	7	18	1	5
832	Cleveland Circle - Government Ctr. Sta.	13	2	6.5	13	1	6	13	1	6	13	2	6.5	7	1	10	16	1	5	11	1	7
850	Riverside - Lechmere Sta.	26	2	4.5	12	2	10	12	2	10	27	2	4.5	11	1	10	20	1	6	18	1	7
880	Heath Sta. - Lechmere Sta.	13	2	6.5	8	2	9	8	2	9	10	2	8.5	8	1	10	10	2	7	14	1	5
RAD	Boston College										1	2	X	1	1	X				1	1	X
RAD	Lechmere																					
RAD	Riverside	1	2	X							1	2	X				2	1	X	2	1	X
RAD	Cleveland Circle	2	2	X							1	2	X	1	1	X	2	1	X	1	1	X
	TOTAL CARS:	**151**			**77**			**77**			**148**			**39**			**90**			**64**		

NOTES:

V = VEHICLES
C = CARS PER TRAIN
H = HEADWAY
X = IRREGULAR HEADWAY
RAD = RUN AS DIRECTED

After simulating the 30% frequency increase described above (four additional trains in the two-hour peak period), the maximum hourly throughput at Copley Junction showed a small increase of one eastbound train, from 44 to 45, while the number of westbound trains stayed the same, at 49. The extra scheduled trains were not reflected in actual throughput, indicating that current Green Line operations are at capacity through Copley Junction during the peak period. Adding this service on the “E” Line would therefore require commensurate service reductions on the other three Green Line branches, as the simulation found that there was inadequate capacity to support the four additional “E” Line trips.

Because the throughput does not increase proportionally with the scheduled frequency, an increase in scheduled “E” Line trains would result in slightly slower operating speeds and longer travel times for Green Line passengers. Indeed, the addition of the extra trains increased average delay per train on the Green Line from 44 seconds to 50 seconds. The effect of the service increase essentially is to allow only a slightly higher number of passengers to pass through Copley Junction per hour, with the passengers “warehoused” onto slow moving trains rather than waiting longer headways for slightly faster trains. While throughput or travel time may not be significantly improved, the addition of more trains might be necessary nevertheless to avoid overcrowding on trains that could come with a projected ridership increase.

6.1 The Three-Car Simulation

As part of the Green Line Operations Improvement Study, SYSTRA developed three different three-car operating scenarios, including:

- *Existing Fleet Size*: Based upon the current operating plan fleet requirement of about 147 cars, only three-car trainsets were operated during peak periods. There was no increase from the current fleet size, with an associated peak period reduction in service frequency.
- *162 Car Fleet Requirement*: Three-car trainsets are implemented on all four Lines, and the peak fleet requirement is increased modestly by about 15 cars.
- *163 Car Fleet Requirement*: Three-car trainsets are implemented only on the Riverside "D" Line. This scenario also includes changes in train route terminal pairings, and changes to frequencies on all lines. The peak fleet requirement increases by about 16 cars from the current car requirement.

Simulations performed as part of the Green Line Operations Improvement Study, which were based on the existing "E" Line service levels found that the 162 Car Fleet Requirement scenario performed best in the Central Subway. Therefore, this operating scenario, detailed below, was selected for additional analysis of increased "E" Line service levels.

While in the 2-car scenario peak hour headways on the "E" Line are shorter than morning base headways, the baseline 3-car scenario has the "E" Line running on 12 minute headways during the morning peak, considerably longer than the 9 minute headways during the morning base.

7. BASELINE SERVICE PLAN FOR 3-CAR OPERATIONS

		WEEKDAY															WEEKEND					
Rte.		**A.M. PEAK**			**A.M. BASE**			**P.M. BASE**			**P.M. PEAK**			**LATE**			**SAT PEAK**			**SUN PEAK**		
No.	**Terminals**	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.
	LIGHT RAIL DIVISION																					
	RESERVOIR STATION																					
812	Boston College -Government Ctr. Sta.	16	3	7	12	2	8	12	2	8.5	15	3	7	11	1	10	15	2	7	18	1	5
832	Cleveland Circle - Government Ctr. Sta.	9	3	9	13	1	6	13	1	6	9	3	9	7	1	10	16	1	5	11	1	7
850	Riverside - Lechmere Sta.	19	3	6	12	2	10	12	2	10	20	3	6	11	1	10	20	1	6	18	1	7
880	Heath Sta. - Lechmere Sta.	7	3	12	8	2	9	8	2	9	7	3	12	8	1	10	10	2	7	14	1	5
RAD	Boston College										1	3	X	1	1	X				1	1	X
RAD	Lechmere																					
RAD	Riverside	1	3	X							1	3	X				2	1	X	2	1	X
RAD	Cleveland Circle	2	3	X							1	3	X	1	1	X	2	1	X	1	1	X
	TOTAL CARS:	**162**			**77**			**77**			**148**			**39**			**90**			**64**		

NOTES:

V = VEHICLES
C = CARS PER TRAIN
H = HEADWAY
X = IRREGULAR HEADWAY
RAD = RUN AS DIRECTED

Increasing the frequency of E trains in the peak by the same factor of 30% evens out this discrepancy, resulting in constant 9 minute headways throughout the morning.

8. 3 –CAR SERVICE PLAN FOR 9-MINUTE AM PEAK HEADWAYS ON “E” LINE

		WEEKDAY															WEEKEND					
Rte. No.	**Terminals**	**A.M. PEAK**			**A.M. BASE**			**P.M. BASE**			**P.M. PEAK**			**LATE**			**SAT PEAK**			**SUN PEAK**		
		V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.	V.	C.	H.
	LIGHT RAIL DIVISION																					
	RESERVOIR STATION																					
812	Boston College -Government Ctr. Sta.	16	3	7	12	2	8	12	2	8.5	15	3	7	11	1	10	15	2	7	18	1	5
832	Cleveland Circle - Government Ctr. Sta.	9	3	9	13	1	6	13	1	6	9	3	9	7	1	10	16	1	5	11	1	7
850	Riverside - Lechmere Sta.	19	3	6	12	2	10	12	2	10	20	3	6	11	1	10	20	1	6	18	1	7
880	Heath Sta. - Lechmere Sta.	10	3	9	8	2	9	8	2	9	7	3	12	8	1	10	10	2	7	14	1	5
RAD	Boston College										1	3	X	1	1	X				1	1	X
RAD	Lechmere																					
RAD	Riverside	1	3	X							1	3	X				2	1	X	2	1	X
RAD	Cleveland Circle	2	3	X							1	3	X	1	1	X	2	1	X	1	1	X
	TOTAL CARS:	**171**			**77**			**77**			**148**			**39**			**90**			**64**		

NOTES:

V = VEHICLES
C = CARS PER TRAIN
H = HEADWAY
X = IRREGULAR HEADWAY
RAD = RUN AS DIRECTED

The baseline 3-car simulation (based on the 162 Car Fleet Requirement) achieves a maximum throughput of 76 trains per hour at Copley, between 9:33 and 10:33, with 36 trains eastbound and 40 trains westbound. With constant 9 minute headways, the peak throughput is actually reduced by one westbound train, while the number of eastbound trains remains 36.

The simulation results show that Copley Interlocking is operating at capacity. Moreover, the addition of service actually reduces throughput, because of the crossing conflicts of outbound “E” Line trains blocking inbound service on the other three lines. The capacities, expressed in trains per hour, of the 3-car scenario are somewhat lower than the corresponding 2-car scenario. This is primarily because of the loss of double berthing at stations; however, because each 3-car train can carry more passengers, the actual passenger throughput is higher. An additional cause of the reduction in trains per hour under the 3-car scenario is the longer physical length of the trains being operated.

With 3-car operation the future standard on the Green Line, an increase in service on the “E” Line will require not only a commensurate peak period reduction on the other three Green Line branches, but may require more than a “one for one” service reallocation. This is because of the physical configuration of Copley Junction, where outbound “E” Line trains consume both outbound and inbound operating slots due to the diamond crossing configuration of the junction.

Conclusions

These results indicate that 3-car trains provide an overall system increase in passenger-carrying capacity on the Green Line when compared with a 2-car train standard. The table below summarizes the results of the four simulations:

Green Line Morning Peak Maximum Hourly Throughput

Scenario	**E Line Headway**	**Trains per Hour**	**Cars per Hour**
2-Car Base	8.5	93	186
2-Car + 30% on "E"	6	94	188
3-Car Base	12	76	228
3-Car + 30% on "E"	9	75	225

After the 30% frequency increase, the maximum hourly throughput at Copley Junction showed a small increase of one eastbound train, from 44 to 45, while the number of westbound trains stayed the same, at 49. The extra scheduled two trains per hour (four in total) were thus not fully reflected in actual throughput.

These results indicate that current Green Line operations are at capacity through Copley Junction during the peak period. Increasing service on the "E" Line would therefore require commensurate service reductions on the other three Green Line branches, as the simulation found that there was inadequate capacity to support the four additional "E" Line trips.

With 3-car operating on the Green Line, Copley Junction achieves a maximum throughput of 76 trains per hour at Copley, between 9:33 and 10:33, with 36 trains eastbound and 40 trains westbound under "baseline" operations. With "E" Line service frequencies increased to a constant 9-minute headway (representing a hypothetical 30 percent service increase to reflect service restoration to Arborway), the peak throughput is actually reduced by one westbound train, while the number of eastbound trains remains 36.

These additional simulation results show that Copley Interlocking is operating at capacity under 3-car operation. Moreover, the addition of service actually reduces throughput, because of the crossing conflicts of outbound "E" Line trains blocking inbound service on the other three lines.

With 3-car operation the future standard on the Green Line, an increase in service on the "E" Line will require not only a commensurate peak period reduction on the other three Green Line branches, but may require more than a "one for one" service reallocation. In other words, for the addition of each "E" line train, it may be necessary to remove more than one train on one of the other three Green Line branches. This is because of the physical configuration of Copley Junction, where outbound "E" Line trains consume both outbound and inbound operating slots due to the diamond crossing configuration of the junction.